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Changes in Stem Quality on Young Thinned Hardwoods

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The Author

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Abstract

Describes changes in limb-related defects on 18-year-old, even-aged hardwoods 6 years after thinning. Stocking levels of 30, 45, and 60 percent were studied. There were fewer defects per square foot of surface area in the higher stocking plots than in the lower stocking plots. The average number of live limbs decreased by 83 percent in the unthinned plots and increased slightly in the heavily thinned plots. The results show that the frequency and size of limb-related defects are affected by stand density over a short period of time.

Introduction

Manipulating stand density is one way to improve the quality of young hardwood stems. Various thinning schemes have successfully improved the quality of some hardwood stems by reducing the number of defects that normally occur. Although some trees inherently develop fewer defects than others, the majority of the commercial species do not fall into this category. Sometimes, trees develop poor stem quantity when extensive thinning methods are used to improve volume growth. However, moderate stand density reduces the adverse effects. For example, Godman and Brooks (1971) found that northern hardwood stem quality of pole-size trees improved after 15 years of treatment at 85 square feet of basal area per acre. This provided a compromise between good quality improvement and a substantial growth rate. In a more recent study on young white oak crop trees by Dale and Sonderman (1984), similar effects were found on thinning methods above C-level stocking where tree quality was not markedly affected, and in some instances, did improve with increased stand density. Sonderman (1984) found that in mixed central hardwoods, the number of limb-related defects per square foot of surface area increased by 6 percent over the control in plots thinned to 30 percent in only 6 years. Limb-related defects are one of the greatest deterrents to stem quality and should be an important consideration in the management of a stand.

In this study, changes in limb-related characteristics were analyzed over a 6-year period after initial thinning. Species, age, site, and stocking levels are the most important factors that affect potential stem quality. Limb-related defects that are measured on each tree, such as live limbs, dead limbs, and epicormic branches, should be considered simultaneously when interpreting the results because a progression of biological events is taking place. That is, epicormic branches grow into live limbs that die and become dead limbs. After dropping-off, the dead limbs form overgrowths. The length of the cycle depends on the stocking levels and ages of the trees.

The Stand

The study plots are located on the Vinton Furnace Experimental Forest in southern Ohio. The 18-year-old even-aged stand had its origin as a result of a circular clearcut made as part of a "size of opening" study established in 1959. It is 5 acres in size, a good cove hardwood site, a northeast facing slope, and approximately a 75 to 80 site index for northern red oak.

The study consisted of twenty 1/10-acre plots, representing three thinning treatments of 30, 45, and 60 percent stocking. A control was established plus a 1/2-chain-wide isolation strip that surrounded each treatment boundary. Stocking was determined by the tree area ratio equation for mixed oaks developed by Gingrich (1967). A stratified sample of 154 trees, randomly selected, came from four species groups: oaks, yellow-poplar, red maple, and a miscellaneous group. The last group consisted of hickory, ash, black cherry, black-gum, and red elm. An aspen group was eliminated from the analysis because of an inadequate number of sample trees.

Methods

External tree characteristics were systematically measured by the quality classification system (Sonderman 1979) on sample trees 3.6 inches or larger in diameter at breast height (d.b.h.). The measurements of limb-related surface characteristics were recorded from the first and second 8-foot section of the butt 16-foot log on each tree at initial thinning in 1977 and again in 1983. These surface characteristics include:

- d.b.h.
- total height
- crown ratio
- number of live limbs on the first and second 8-foot section of the butt 16-foot log
- number of dead limbs on the first and second 8-foot section of the butt 16-foot log
- diameter of the largest live limb on the first and second 8-foot section of the butt 16-foot log
- diameter of the largest dead limb on the first and second 8-foot section of the butt 16-foot log
- number of epicormic branches on the first and second 8-foot section of the butt 16-foot log

In this study, epicormic branches were grouped to facilitate counting: 0 = No epicormic branches, 1 = 1 to 6 epicormic branches, and 2 = 7 or more epicormic branches.

The branch had to be 0.3 inch or more diameter at the base to qualify as a measurable live or dead limb; otherwise, it was considered an epicormic branch. All stem defects were summarized by species, plot, and stocking level. Covariance analysis was used to test the limb-related variables; the value of the variable at initial time was used as the covariate.

Results and Discussion

Diameter Growth

Thinning hardwood stands to different density levels affects the diameter growth of the residual trees. The data in Figure 1 show a decrease in the average diameter growth as the stocking increases. When analyzed for all species combined, the change from 1977 to 1983 in average diameter growth was: 3.5 inches in the 30 percent stocking, 2.5 inches in the 45 percent stocking, 2.3 inches in the 60 percent stocking, and only 2.0 inches in the control. Yellow-poplar was the single fastest growing species, increasing 3.8 inches in diameter in the 30 percent stocking plots and only 2.8 inches in the control. The next fastest growing species was red maple, followed last by the oak group.

Height Growth

After thinning, the average total height for all species combined decreased as the stocking level increased (Fig. 2). From 61.5 feet in the 30 percent stocking, average height decreased to 61.0 feet in the 45 percent stocking, 57.5 feet in the 60 percent stocking, and 55.2 feet in the control. The largest change in height growth for all species combined from 1977 to 1983 was in the 45 percent stocking plots, averaging over 3 feet per year. The trend was similar for individual species. One of these, yellow-poplar, outgrew all other species, in the 45 percent stocking plots. Other studies on tree quality (Sonderman 1985) involving tree heights in relation to stocking have shown similar trends resulting in maximum height growth change in the 45 to 70 percent stocking.

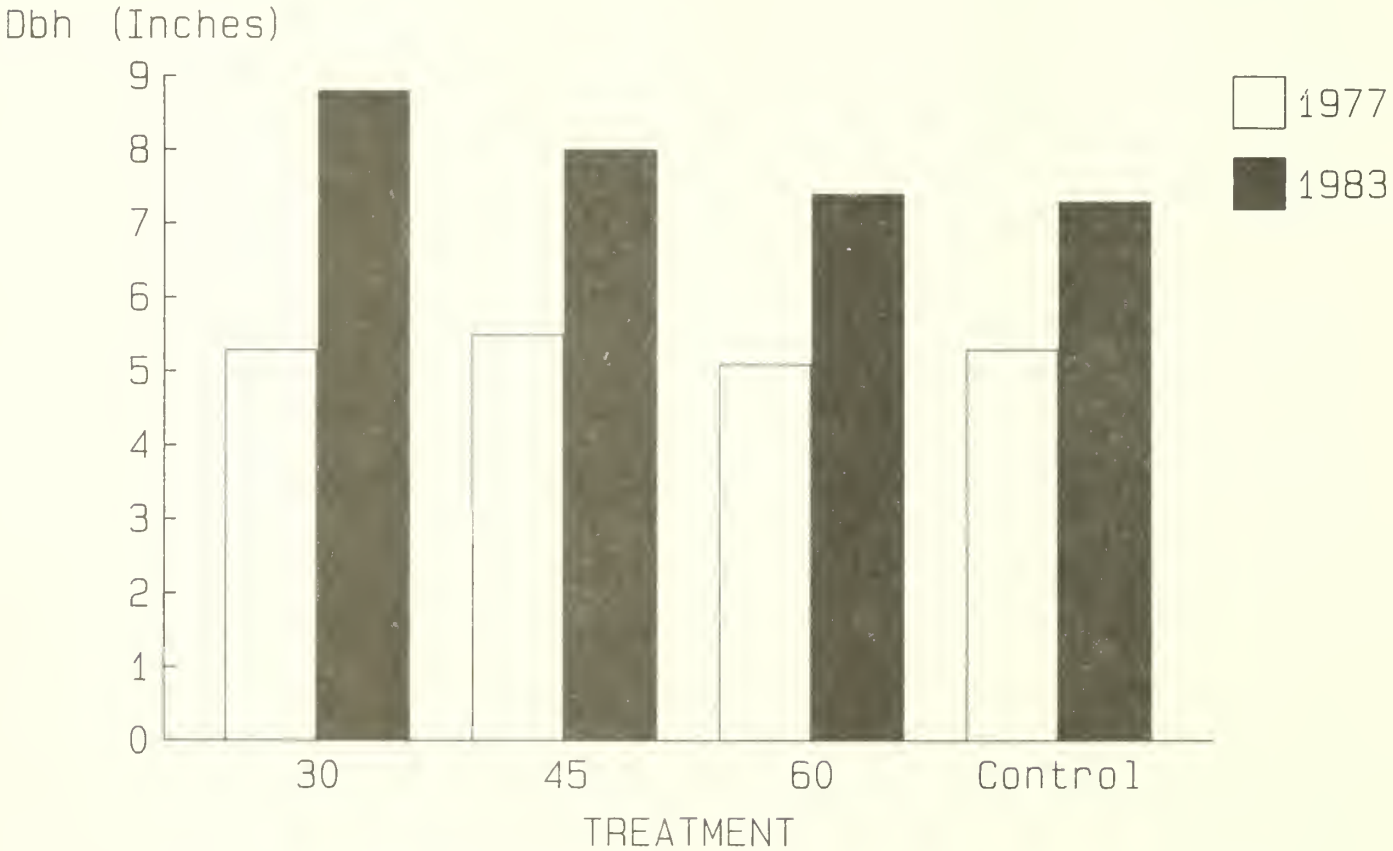

Figure 1.—Average d.b.h. for all species combined by treatment—1977-83.

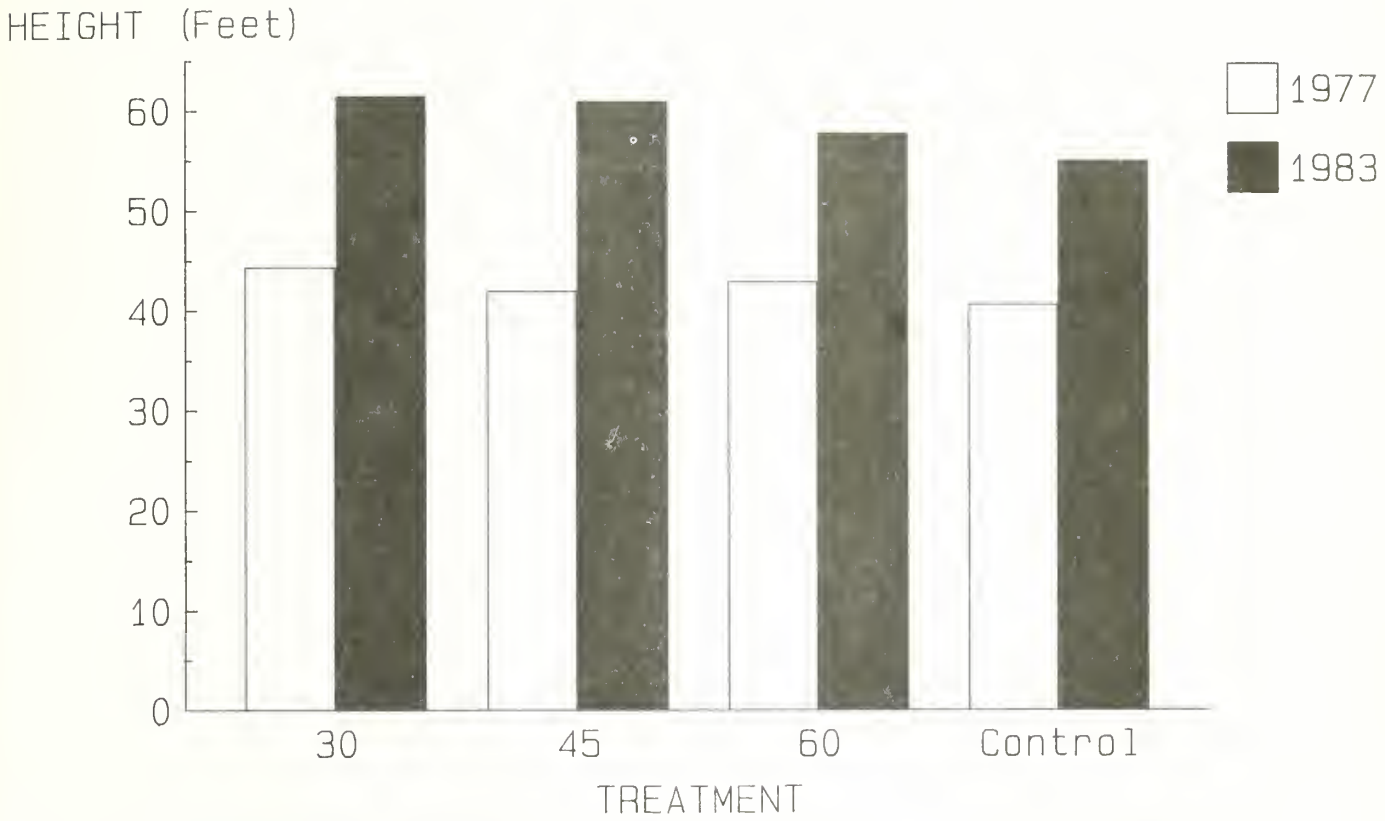

Figure 2.—Average height for all species combined by treatment—1977-83.

Crown Ratio

Crown ratio is the ratio of live crown length to total height of the tree. It is usually one of the best indicators of the effects of stand density on stem quality. For all species combined, the average crown ratio increased slightly in the plots with 30 and 45 percent stocking from 1977 to 1983, and remained about the same in the 60 percent and control plots (Fig. 3). During those 6 years, the heavily thinned plots with open crown canopies and much light from above influenced the crown ratios of many study trees. In many instances, there was a downard extension of the crown that resulted in an increase in epicormic branching and live limb development.

Live and Dead Limb Defects per Square Foot of Surface Area

As tree d.b.h. expands, so does the surface area. Live and dead limb defects per square foot of surface area generally decrease as the tree grows and the surface area expands—if no new defects develop. In this study, the heavily thinned plots showed an increase in the number of defects per square foot of surface area even though surface area greatly increased. Therefore, these plots developed many new limb-related stem defects in only 6 years.

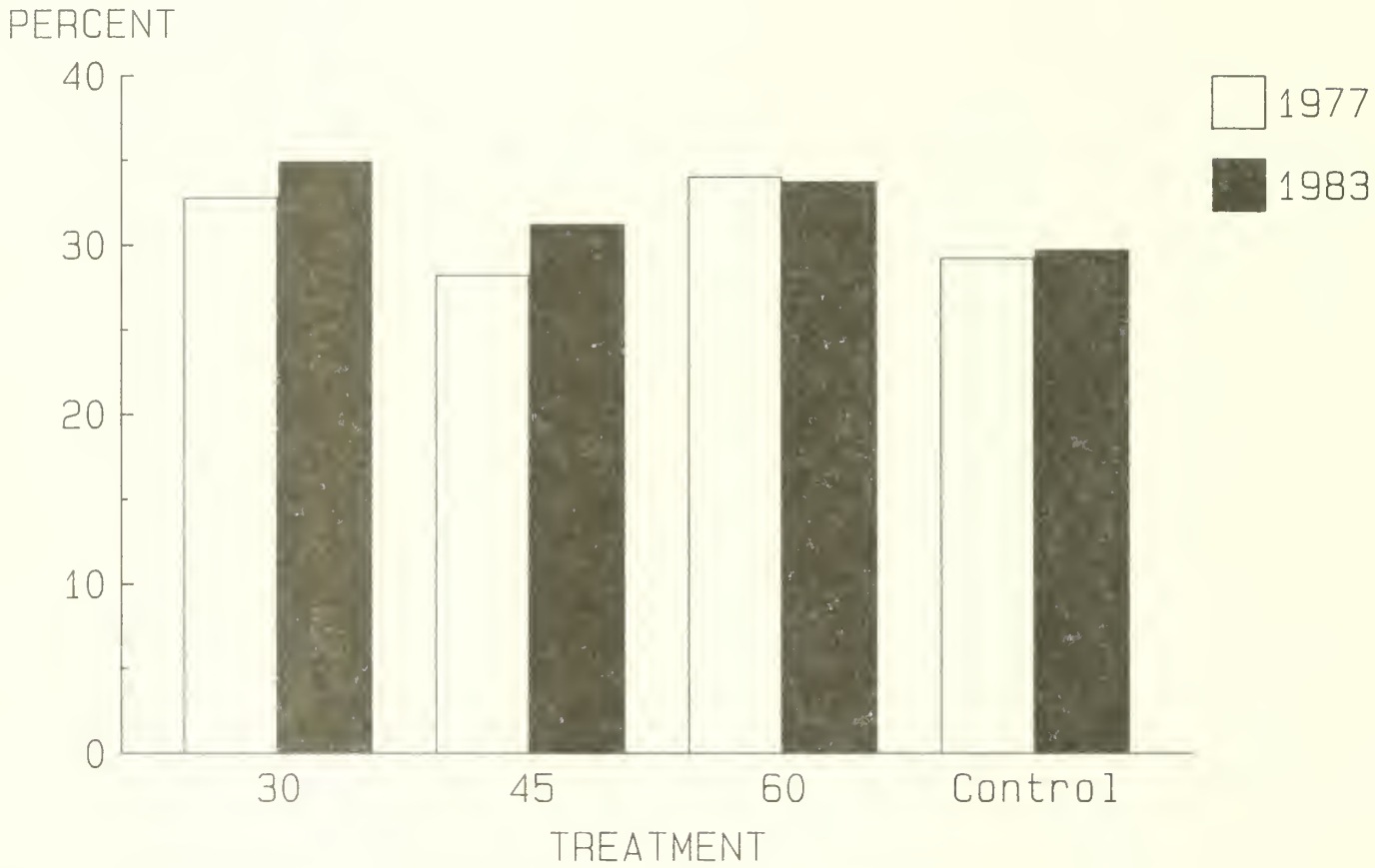

Figure 3.—Average crown ratio, in percent, for all species combined by treatment—1977-83.

The analysis showed that surface area increases for all species combined between 1977 and 1983 from lowest to highest stocking levels were 64, 45, 47, and 39 percent, respectively. In comparison, the number of defects per square foot of surface area for all species combined between 1977 and 1983 is:

Stocking Treatment (%)

Year	*30*	*45*	*60*	*Control*
1977	0.201	0.169	0.264	0.264
1983	0.109	0.060	0.079	0.104

Comparison of live and dead limb defects per square foot of surface area (butt 16-foot section) for all species combined after 6 years showed that the 30 percent stocking plots had a significantly greater number of defects than the other stocking plots ($P<0.12$) when tested by covariance analysis.

Epicormic Branches

Thinning a stand heavily often opens the crown canopy to light which stimulates suppressed buds that may develop into epicormic branches on some tree species. In many instances, these branches will continue to grow into small live limbs so long as light is abundant.

In this study, few of the trees had epicormic branches when first measured in 1977. Six years after thinning, however, the percentage of trees with epicormic branches had increased in all stocking plots (Fig. 4). The 60 percent stocking level had the largest increase in the number of epicormic branches found in the butt 16-foot log. This large change resulted partially from a high proportion of red maple trees in this stocking level. Red maples are prolific sprouters, and almost half of them in the plots with 60 percent stocking had seven or more epicormic branches when meas-

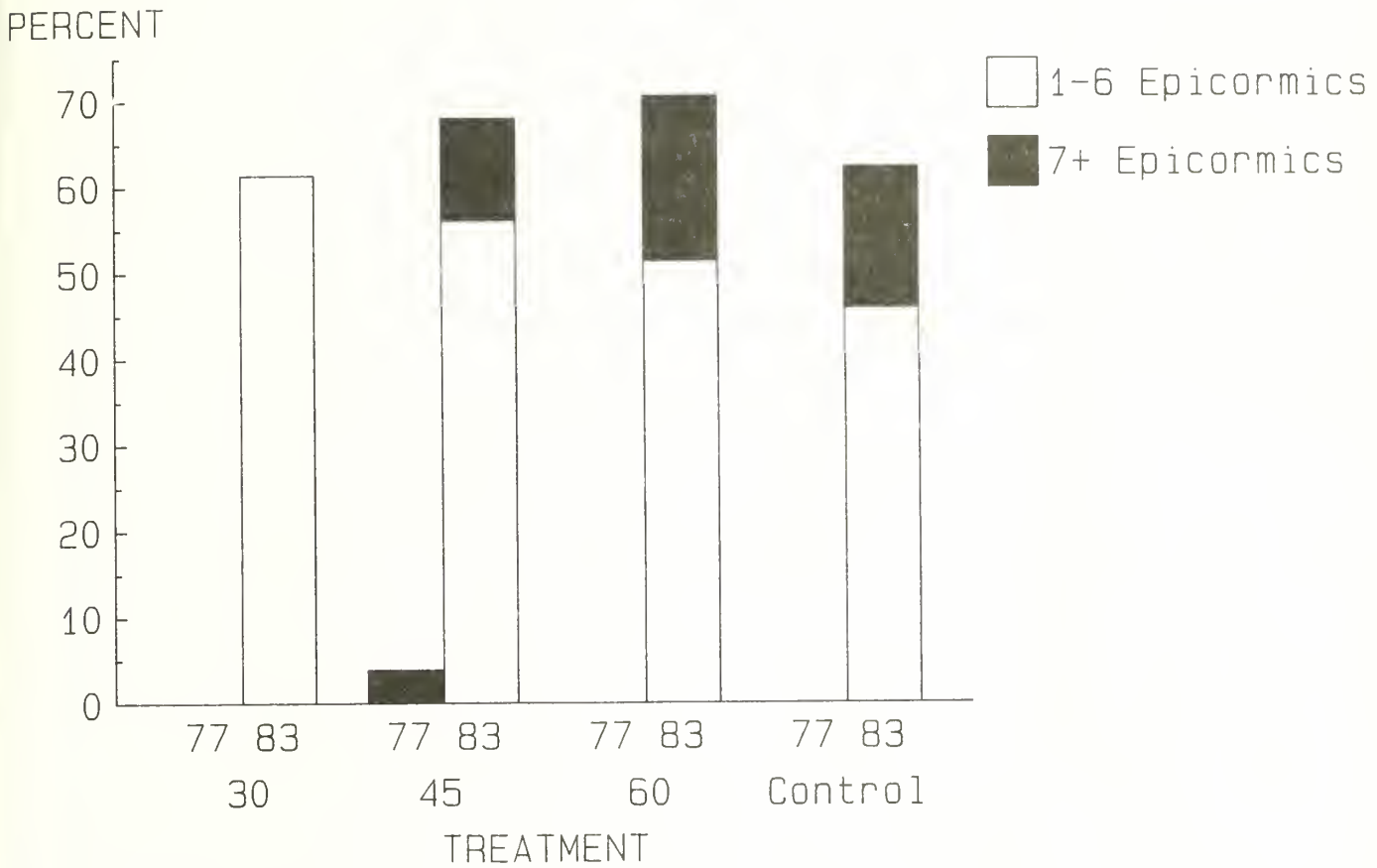

Figure 4.—Percentage of trees with epicormic branches for all species combined (butt 16-foot section) by treatment—1977-83.

ured in 1983 (Table 1). Similarly, more than one-half of the red maples in the control plots had seven or more epicormic branches in the same amount of time. In comparison, yellow-poplar in the 60 percent stocking plots made up less than 10 percent of the trees having seven or more epicormic branches and had none in the control.

Live Limbs

None of the trees in any of the stocking plots had live limbs in 1977 when the butt 8-foot section was analyzed. However, by 1983 many trees in the 30 percent stocking plots had grown new live limbs, but the control plots remained free.

For all species combined, the average number of live limbs (Table 2) in the second 8-foot section increased the most in the 30 percent stocking plots and decreased by 83 percent in the control plots. The size of the live limbs (Table 3) for all species combined in the 30 percent stocking plots decreased by 23 percent from 1977 to 1983, but increased only 1 percent in the control. As a rule, the second 8-foot section of the butt 16-foot log usually will contain more and larger live limbs than the butt 8-foot section.

Treatment differences for live limbs in the butt 16-foot section for all species were significant ($P<0.01$). In the butt 16-foot section, the 30 percent stocking plots had an increase of 0.7 live limbs, and the control plots had a loss of 0.6 live limbs.

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Table 1.—Percent of trees with epicormic branches in the butt 16-foot section, 1977-83, by species

Number of epicormic branches	Stocking level (%)							
	30		45		60		Control	
	1977	1983	1977	1983	1977	1983	1977	1983
				OAK				
0	100.0	—	100.0	—	(No Trees)		100.0	—
1-6	—	100.0	—	—	—	—	—	50.0
7+	—	—	—	100.0	—	—	—	50.0
				YELLOW-POPLAR				
0	100.0	41.4	100.0	40.0	100.0	9.2	100.0	46.2
1-6	—	58.6	—	60.0	—	81.8	—	53.8
7+	—	—	—	—	—	9.0	—	—
				RED MAPLE				
0	100.0	33.4	80.0	20.0	100.0	15.9	100.0	14.4
1-6	—	66.6	—	60.0	—	36.8	—	28.5
7+	—	—	20.0	20.0	—	47.3	—	57.1
				MISCELLANEOUS[a]				
0	100.0	16.7	100.0	33.4	100.0	70.6	100.0	50.0
1-6	—	83.3	—	55.5	—	29.4	—	50.0
7+	—	—	—	11.1	—	—	—	—
				ALL				
0	100.0	35.9	96.0	32.0	100.0	29.4	100.0	37.6
1-6	—	64.1	—	56.0	—	51.7	—	46.8
7+	—	—	4.0	12.0	—	18.9	—	15.6

[a]Miscellaneous group includes hickory, ash, black cherry, blackgum, and red elm.

Table 2.—Average number of live limbs in the butt and second 8-foot sections, 1977-83, by species group

Species group	Stocking level (%)							
	30		45		60		Control	
	1977	1983	1977	1983	1977	1983	1977	1983
				BUTT 8-FOOT SECTION				
Oaks	—	1.76	—	—	(No trees)		—	—
Yellow-poplar	—	.44	—	0.21	—	0.09	—	—
Red maple	—	1.47	—	—	—	.14	—	—
Miscellaneous[a]	—	—	—	.29	—	—	—	—
All	—	.47	—	.20	—	.08	—	—
				SECOND 8-FOOT SECTION				
Oaks	—	6.79	—	—	(No trees)		6.93	—
Yellow-poplar	2.04	2.88	0.99	0.57	1.95	0.23	.86	0.16
Red maple	6.90	5.51	.87	2.06	2.51	1.67	4.90	—
Miscellaneous[a]	.46	.45	.83	.74	.40	.60	1.63	.98
All	2.18	2.79	.87	1.03	1.75	.87	2.52	.42

[a]Miscellaneous group includes hickory, ash, black cherry, blackgum, and red elm.

Table 3.—Average diameter, in inches, of the largest live limbs in the butt and second 8-foot sections, 1977-83, by species group

Species group	Stocking level (%)							
	30		45		60		Control	
	1977	1983	1977	1983	1977	1983	1977	1983
	BUTT 8-FOOT SECTION							
Oak	—	0.75	—	—	(No trees)		—	—
Yellow-poplar	—	.55	—	1.25	—	3.00	—	—
Red maple	—	1.00	—	—	—	.50	—	—
Miscellaneous[a]	—	—	—	.50	—	—	—	—
All	—	.64	—	.87	—	1.75	—	—
	SECOND 8-FOOT SECTION							
Oak	—	0.75	—	—	(No trees)		1.00	—
Yellow-poplar	1.00	.64	0.87	1.00	0.92	1.00	1.91	2.00
Red maple	1.37	1.62	2.00	1.16	1.05	1.09	.87	—
Miscellaneous[a]	1.75	2.50	.87	.62	1.41	.50	1.35	1.06
All	1.15	.89	1.10	.95	1.06	.97	1.23	1.25

[a]Miscellaneous group includes hickory, ash, black cherry, blackgum, and red elm.

Dead Limbs

The average number of dead limbs (Table 4) for all species combined in the second 8-foot section decreased in all stocking plots from 1977 to 1983. However, the numbers of dead limbs in the control plots did not decrease as much as those in the other stocking plots. This was due partially to the larger average size of the dead limbs in the control plots. In fact, the average size of the largest dead limbs for all species combined (Table 5) occurred in the control plots where they increased by 49 percent as opposed to a 22 percent decrease in size in the 30 percent stocking plots. Large dead limbs, when they reach a certain size, do not prune-off easily even in the unthinned plots.

Summary and Conclusion

Limb-related defects are the major cause of degrading stem quality in young hardwood trees. It is improbable that all defects can be prevented; so, the results of this study may provide the land manager with enough information on stand density choices to reduce stem-defect occurrence and numbers. To do this, forest management decisions should be based on the best residual stand densities needed to grow high-quality trees at fast volume growth. The results of these data show that the heavily thinned stands usually have good diameter growth, large numbers of stem defects, and big crowns. Therefore, stand densities should be held above C-level stocking to maintain tree quality.

Table 4.—Average number of dead limbs in the butt and second 8-foot sections, 1977–83, by species group

Species group	Stocking level (%)							
	30		45		60		Control	
	1977	1983	1977	1983	1977	1983	1977	1983
	BUTT 8-FOOT SECTION							
Oak	—	—	—	—	(No trees)		3.60	0.94
Yellow-poplar	0.12	0.94	—	0.36	0.85	0.09	.28	.19
Red maple	4.01	—	1.22	—	1.27	.28	1.28	—
Miscellaneous[a]	1.28	.84	.66	—	2.03	1.19	2.06	.50
All	.53	.81	.55	.11	1.31	.48	1.39	.34
	SECOND 8-FOOT SECTION							
Oak	18.41	6.79	2.26	—	(No trees)		6.55	4.54
Yellow-poplar	4.34	2.75	4.05	2.98	2.61	1.49	2.16	1.91
Red maple	9.09	2.74	6.88	.83	10.16	2.42	7.40	5.98
Miscellaneous[a]	11.34	5.73	7.37	3.10	10.67	5.75	10.29	7.75
All	5.84	3.32	5.99	2.48	7.36	3.12	6.60	5.32

[a]Miscellaneous group includes hickory, ash, black cherry, blackgum, and red elm.

Table 5.—Average diameter in inches of the largest dead limbs in the butt and second 8-foot sections, 1977–83, by species group

Species group	Stocking level (%)							
	30		45		60		Control	
	1977	1983	1977	1983	1977	1983	1977	1983
	BUTT 8-FOOT SECTION							
Oak	—	—	—	—	(No trees)		0.75	0.50
Yellow-poplar	0.62	0.50	—	0.50	0.95	0.50	1.00	1.00
Red maple	1.00	—	0.75	—	.68	1.00	.62	—
Miscellaneous[a]	1.00	.87	.75	—	.85	.92	1.00	.66
All	.89	.55	.75	.50	.81	.90	.85	.70
	SECOND 8-FOOT SECTION							
Oak	1.00	0.75	0.75	—	(No trees)		1.25	1.25
Yellow-poplar	.72	.61	.84	0.82	0.82	0.86	.91	1.66
Red maple	1.25	.87	.62	1.37	.81	1.02	.85	1.10
Miscellaneous[a]	1.41	.95	.78	1.18	1.08	1.35	.77	1.15
All	.92	.72	.77	1.01	.91	1.11	.85	1.27

[a]Miscellaneous group includes hickory, ash, black cherry, blackgum, and red elm.

Other important results are:

- Diameter (d.b.h) growth increased as the growing space increased.
- Average crown ratio for all species combined increased only in the 30 and 45 percent stocking plots.
- Limb defects per square foot of surface area increased the most in the 30 and 45 percent stocking plots when average surface area was considered.
- The average number of live limbs in the second 8-foot section of the butt 16-foot log decreased as the percent stocking increased.
- Average size of live limbs in the second 8-foot section of the butt 16-foot log was smaller in the lower stocking plots and increased as stocking increased.
- The number of dead limbs in the second 8-foot section of the butt 16-foot log of the control plots did not decrease as much as the dead limbs in the same section of the other stocking plots.
- Average size of dead limbs in the second 8-foot section of the butt 16-foot log decreased in the 30 percent stocking plots and increased in all other stocking plots.
- The unthinned plots had the lowest percentage of trees with epicormic branches in the butt 16-foot section.
- Yellow-poplar increased the most in diameter growth, height growth, and crown ratio of all the species.
- For all trees combined, all stocking levels had some epicormic branches after thinning. The majority of the trees had 1 to 6 epicormic branches.

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Technoeconomic Analysis of Conventional Logging Systems Operating from Stump to Landing

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Abstract

A technoeconomic analysis of timber harvesting systems was conducted to obtain key information for estimating longrun supply trends of roundwood materials from eastern woodlands. Productivity and cost factors for six stump-to-landing systems were developed from operational data for 47 harvesting operations. Technical factors and the effects of financial considerations were also assessed. Combined with the productivity and cost factors, they provided better perception of the forces impacting longrun roundwood supplies and logging contractors' business options.

Introduction

Harvesting is one of the most expensive activities in the production of wood products, and harvesting costs directly influence the demand for stumpage and the supply of roundwood material. Therefore, one key piece of information needed to predict the longrun supply of roundwood materials from eastern woodlands is an analysis of the different systems that are or may be used to harvest timber. In this paper, we have analyzed stump-to-landing functions of six different logging systems employed in eastern forests. Our intent is to obtain a broad perspective of productivity and cost factors for them and to combine this information with technical, financial, and other considerations important in the selection of logging equipment and systems.

This paper is presented in four sections. The first section presents technical and economic information developed from operational data from 47 harvesting studies. The second section presents technical factors that influence the use of a particular harvesting system on a particular site. Section 3 of this paper introduces the effect of the real-world considerations that loggers must face and their potential effect on selection of harvesting equipment and systems. The concluding section summarizes the materials presented in the previous sections and makes suggestions for future research.

Comparative Analysis of Conventional Logging Systems

Six conventional logging systems—horse, mini-tractor, crawler tractor, cable skidder, grapple skidder, and cable yarder—are compared in this section. The data for this analysis came from 25 published and unpublished reports. Altogether, the reports yielded information for 47 logging operations including 6 horse, 5 mini-tractor, 8 small crawler tractor, 10 cable-skidder, 9 grapple-skidder, and 9 small cable-yarder systems. For each logging operation, information was extracted on location, terrain, type of cut, species, mean stand diameter, roundwood products cut, yarding distance, load size per turn, capital cost of equipment, crew size, system cost per day, output per day and per man-day, and cost per unit of output (Appendix, Tables 1 to 6).

Volume of wood harvested was calculated in cords of wood plus bark. If outputs were recorded in other units, appropriate factors were used to convert them to cords. Cost per unit of output for each logging system was developed by summing daily labor and equipment costs and dividing this sum by daily output. For comparison purposes, all wages were fixed at $6/hour plus 31 percent for employer-paid taxes and insurance (= $7.86), and all capital equipment costs were standardized to 1983 dollars using Producer Price Indexes for construction equipment. Machine rates for new equipment were based on ownership and operating

costs per hour as determined by Cubbage (1980), or from data given in the cited reference. Machine utilization factors were based on data in the abstracted papers or from Miyata (1980).

The data base includes terrain that ranges from flat to mountainous and many species, including hardwoods and softwoods. Conditions differ widely among the studies analyzed, but each operation was a legitimate harvest of trees found in forest stands. In that sense, the studies are representative of a population of forest harvesting operations, and the analyses reported here are based on this underlying assumption. Reported inputs and outputs for like harvesting systems were collated and analyzed, means and ranges of data for the six logging systems were compared, and relative inputs, outputs, and costs were assessed.

Description of Logging Operations

Six horse-logging operations, including both single and team hitches of draft horses, were analyzed. All operations were in mountainous terrain, and except for one in New Zealand, all were in the United States. Most were harvests of tree-length hardwoods from a variety of cuttings: thinnings, selection, and clearcuts. The usual crew size was two men—a faller and a teamster. On steep slopes in Montana, the crew used two horses, resting one while the other worked.

Five mini-tractors, ranging in size from 12 to 48 horsepower, extracted tree-length poles from thinnings in the Northeastern States. In all cases, the crew was two men—a faller and a tractor operator.

Small crawler tractors of 42 to 78 hp operated on mountainous logging shows in the central Appalachians, British Columbia, and Washington state, where they thinned and clearcut stands of hardwoods and softwoods. Logging crews consisted of two men—a faller and a tractor operator.

Rubber-tired cable skidders operated on 10 logging shows in West Virginia, Montana, and Mississippi on hilly to mountainous terrain. The skidders were equipped with winches for logging tree-length hardwoods and softwoods. Their engines ranged from 60 to 125 hp; however, most were 90-hp machines. Harvests were thinnings, diameter-limit selection, and clearcuts. Crew size ranged from two to three men—a faller, a chokersetter, and a skidder operator.

Rubber-tired grapple skidders working in conjunction with mechanical fallers of various makes were used on nine whole-tree chipping operations in New England and the Lake States. The terrain was flat to moderately steep (slopes seldom over 15 percent). These skidders ranged from 90 to 152 hp. Harvests were mostly thinnings, extracting whole trees in hardwood and pine stands. Crew size varied from two to four men—one man operating the mechanical faller[1] and up to three men operating grapple skidders.

Small cable-yarding systems were operated on nine logging shows in the Appalachians and the Northwest. The equipment included two jammers and four skyline yarders. Five operations were thinning jobs and the others were clearcuts and residue relogging. Both log-length and tree-length removals were made from stands of hardwoods and Douglas-fir. Crew sizes ranged from three to seven men, including fallers, yarder operators, chokersetters, chasers, and tractor operators on three jobs where swing operations were necessary.

Production and Costs for Logging System Operations

Analyses of production and costs were limited to the two basic, yet complex, logging functions—felling and extraction. (Log loading and transport functions were not included in our analysis.) The analyses were structured so that inputs of labor and machines were restricted to the number of each necessary for a producing unit within a given system. For example, one faller and one chain saw plus one crawler tractor and operator were considered one producing unit in the crawler-tractor system. Production data were based on the unit's output. Cost data were based on the sum of wages and fringe benefit costs for workers and the machine rates for equipment. Auxiliary equipment such as crew trucks, service trucks, bulldozers, welders, spare parts, etc., were not included in determining investment or production costs; nor were costs of stumpage, roadbuilding, landing construction, supervision, or overhead included in any of our cost calculations.

Production and cost data were developed by the method described above for each logging operation within each of the six systems analyzed (Appendix, Tables 1 to 6). Within each system, production and cost data from the individual operations were summed, and means and ranges were calculated. Means and ranges of production and cost data are presented in tabulations and bar charts in the following pages of this section.

[1] Mechanical fallers included both tree-to-tree (TT) and limited-area (LA) types. TT fallers and faller-bunchers must move from tree to tree; LA faller-bunchers have the felling mechanism mounted on a boom that can swing to reach several trees from one position of the carrier.

Average capital investment ranged from a low of $2,318 for horse logging to $256,000 for grapple skidders coupled with mechanical fallers (Fig. 1). Grouped by average dollar investment, the six logging systems rank roughly as shown in the following tabulation:

Capital Investment Categories (thousands)				
<$4	$10-39	$40-69	$70-139	>$264
horse	mini-tractor	crawler cable skidder cable yarder	cable yarder-plus-swing operation	mechanical-faller/ grapple-skidder

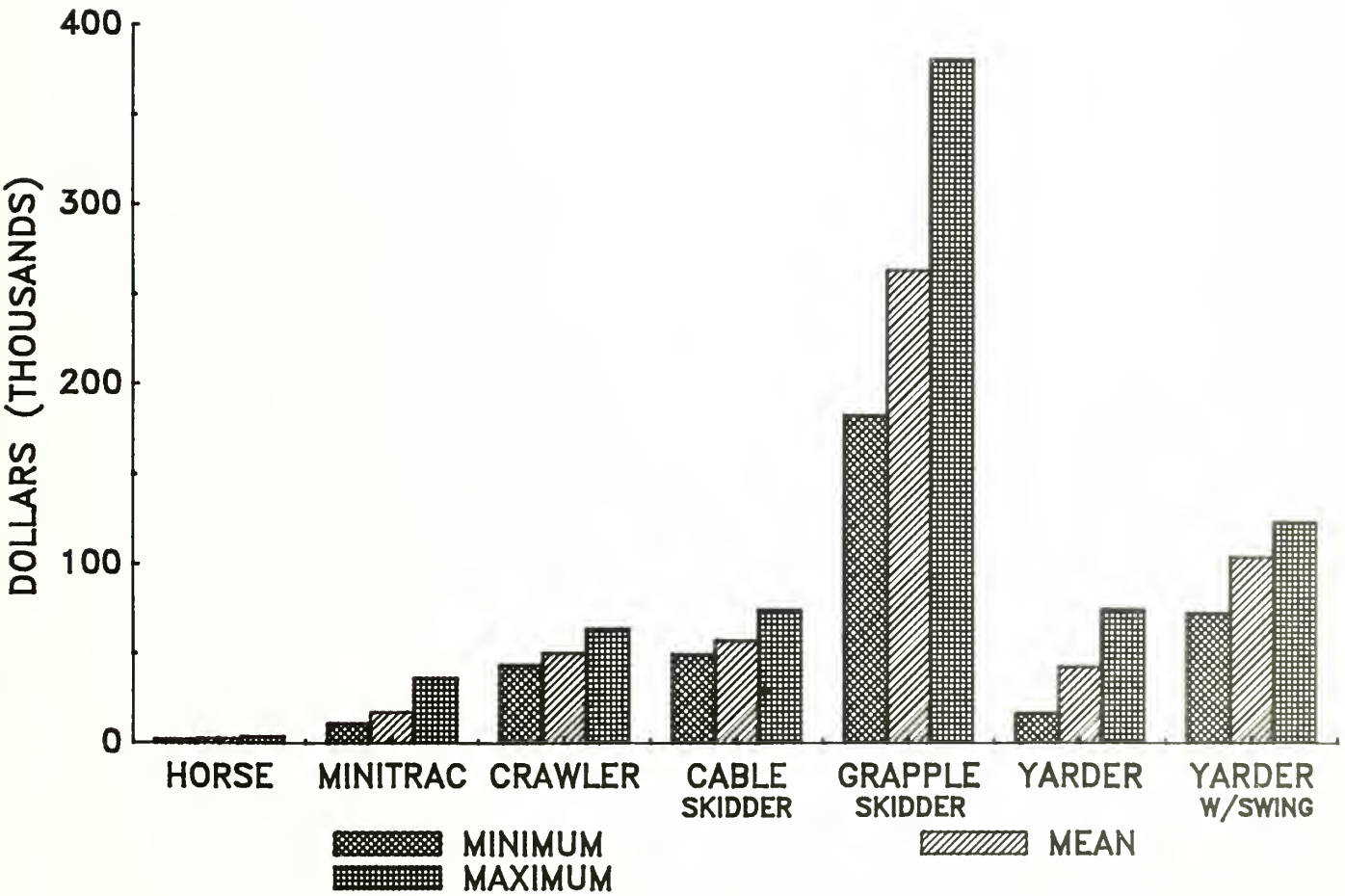

Figure 1.—Capital investment for equipment

Evaluation of dollars spent for labor per hour compared to the hourly cost to own and operate equipment shows that the horse, small cable yarder, and mini-tractor systems are the most labor intensive (Fig. 2). Mechanical-faller/grapple-skidder systems, on the other hand, while requiring the largest capital investment, are the least labor intensive. This system has the highest productivity, with output averaging about 28 cords per man-day (Fig. 3). Systems with low productivity—horse, mini-tractor, and small cable yarder—average 5 cords or less per man-day. And, with the exception of the small cable yarder, these systems rank in the lowest capital investment classes.

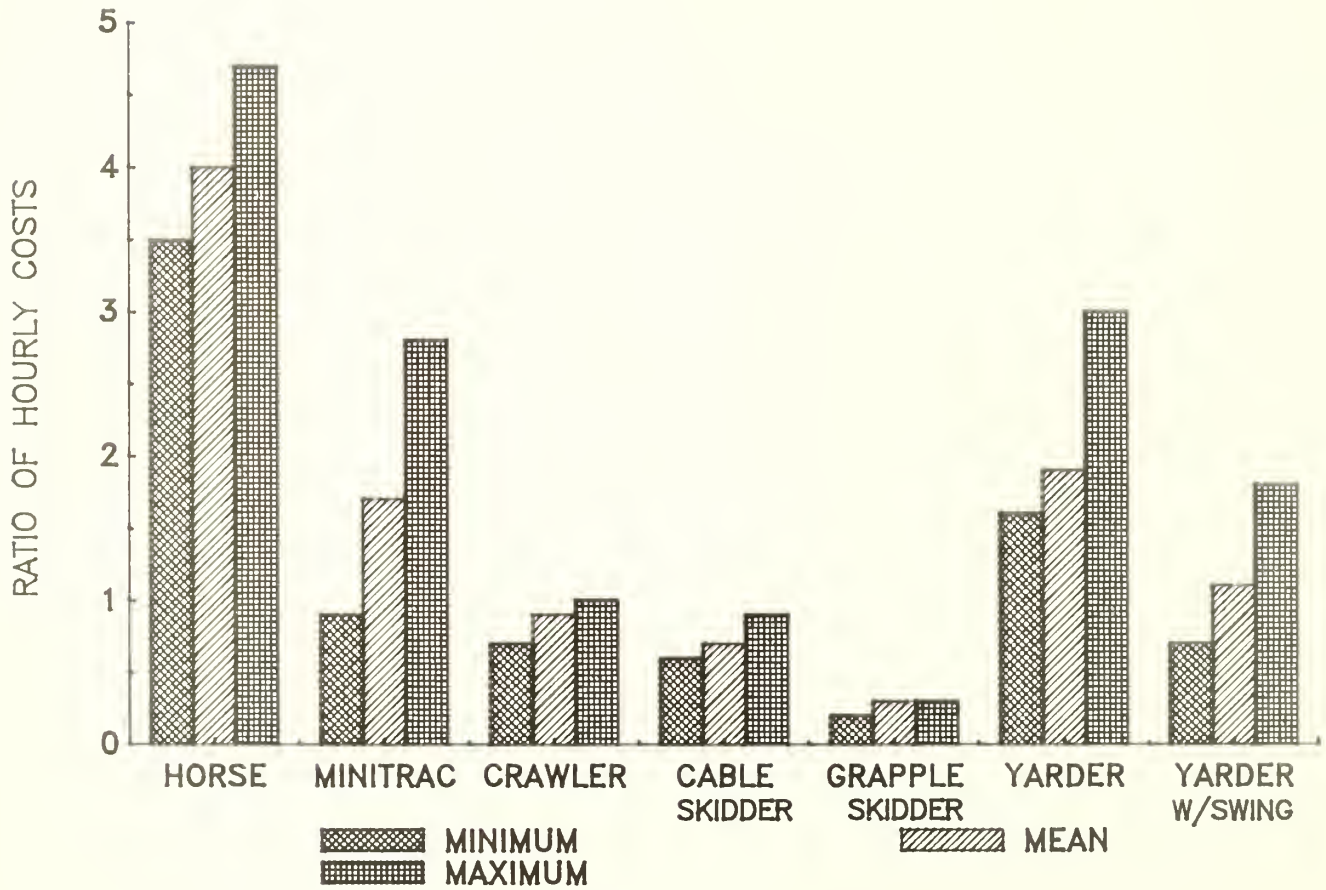

Figure 2.—Ratio of hourly labor costs to hourly equipment costs

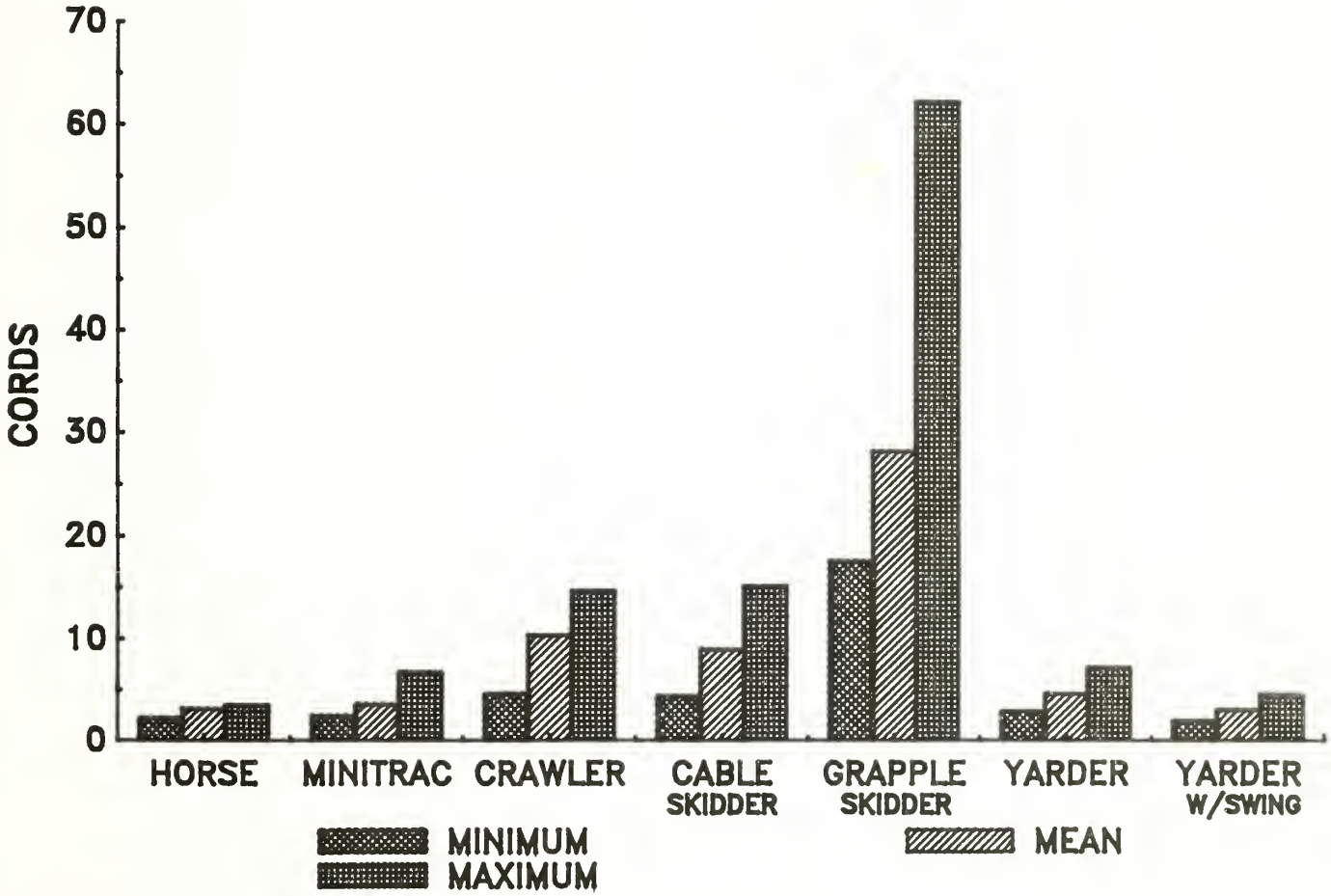

Figure 3.—Production rate per man-day

The daily production rate (Fig. 4) follows much the same pattern as production per man-day. The mechanical-faller/grapple-skidder system produces, on the average, more than three times as much wood as the next most productive system. Average production per day is:

Production Per 8-Hour Day			
<10 cords	*10–19 cords*	*20–29 cords*	*>70 cords*
horse mini-tractor	cable yarder cable yarder-plus-swing operation	crawler cable skidder	mechanical-faller/grapple-skidder

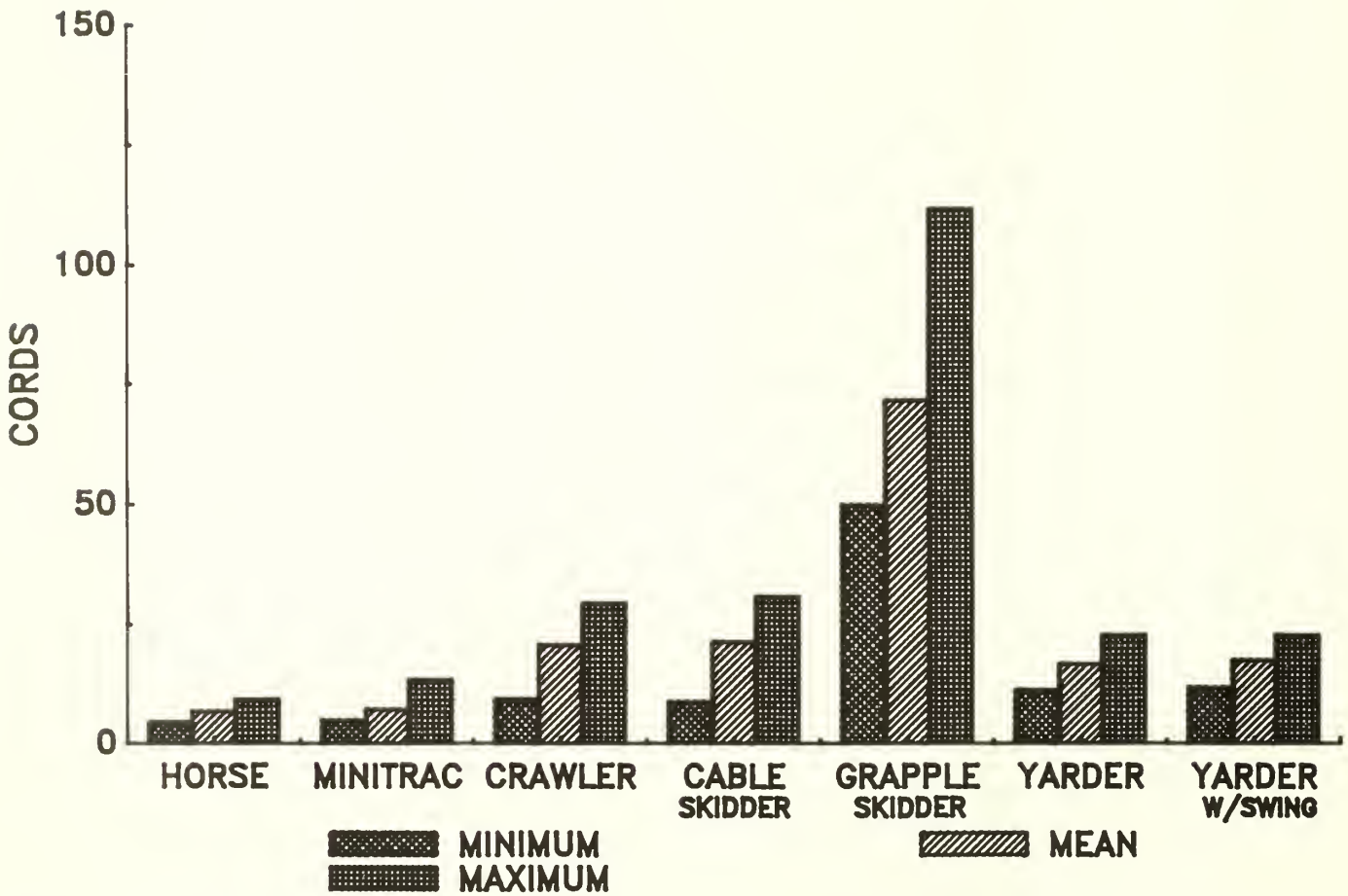

Figure 4.—Production rate per day

The mechanical-faller/grapple-skidder system is, on the average, the most expensive to own and operate, at close to $900 per day, while horse logging averages less than $200 (Fig. 5). The range of average daily costs among the six systems is:

Logging System Owning-and-Operating Cost Per Day			
<$200	*$200–299*	*$300–399*	*$600–899*
horse	mini-tractor crawler	cable skidder cable yarder	mechanical-faller/ grapple-skidder cable yarder-plus- swing operation

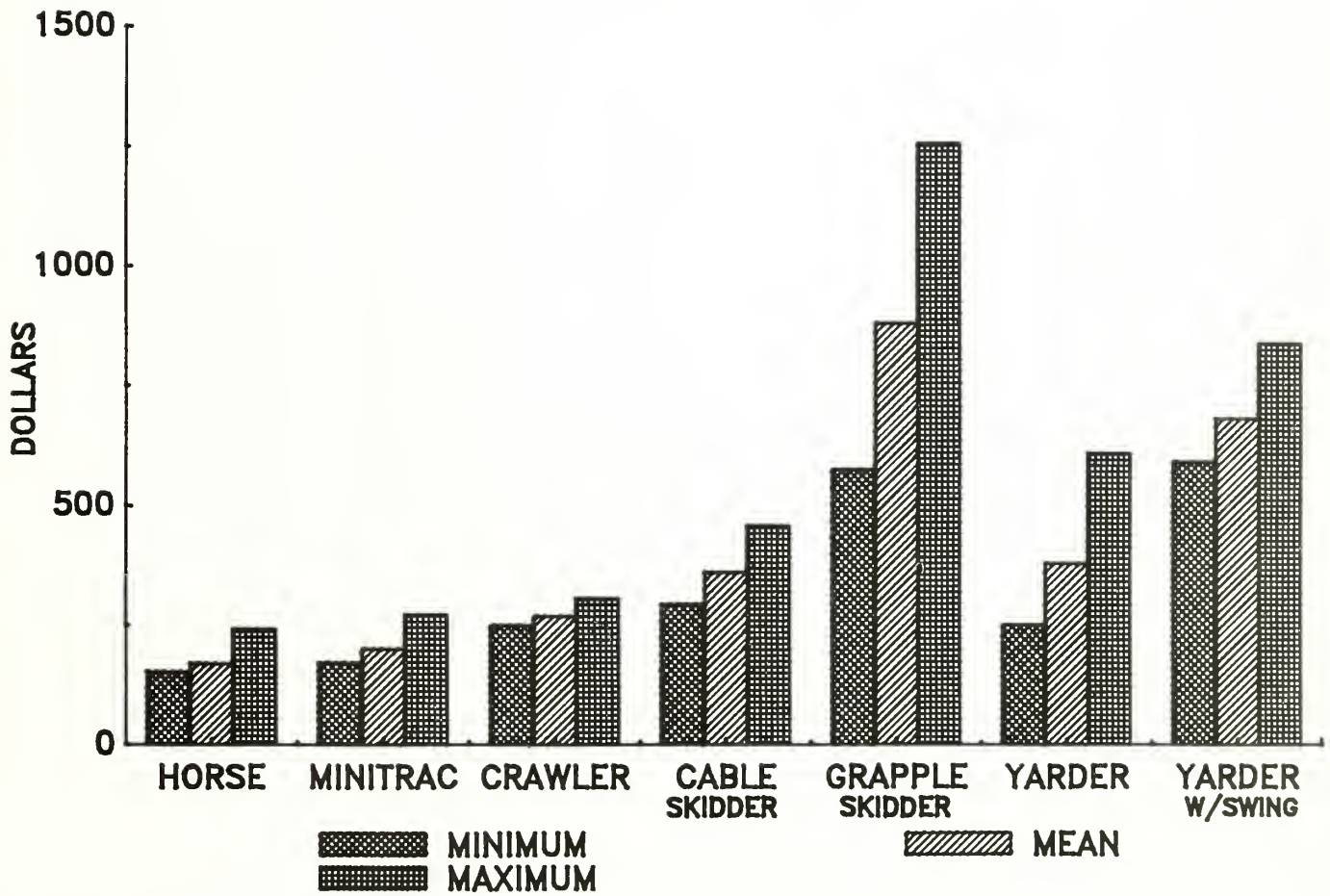

Figure 5.—Logging system cost per day

For each system, manpower and equipment are functions of the balance between the productivities of felling and skidding operations. With chain-saw felling, the usual balance appears to be one faller per producing unit (but this can vary significantly with tree size and skid distance). Productivity of mechanical fallers is two to three times that of chain-saw felling; one faller-buncher unit can keep two to three grapple skidders supplied with whole trees. Hence, instead of two men per producing unit, three to four are required. Nonetheless, productivity per man-day is highest for mechanical-faller/grapple-skidder systems even though larger crews are necessary to man the greater number of machines.

Cable yarding crews are also somewhat larger than skidding crews because of the addition of a chokersetter and a chaser to the usual crew of faller and equipment operator. If a swing operation supplements the cable yarder, a skidder and operator must be added to the crew. In summary, typical crew sizes for felling and yarding operations fall into three categories:

Typical Crew Size

2 to 3 persons	*2 to 4 persons*	*3 to 7 persons*
horse	mechanical-faller/ grapple-skidder	cable yarder
mini-tractor		cable yarder-plus-swing operation
crawler		
cable skidder		

Daily production in cords and total daily costs of labor and equipment were used to determine cost per cord. Average cost per cord among the six logging systems was lowest ($13.03) for the mechanical-faller/grapple-skidder system. Highest average costs were $30.98 and $41.69 per cord for the mini-tractor system and the small cable yarder-plus-swing operation (Fig. 6). Average costs per cord for the other systems fell in between these extremes:

Logging System Cost Per Cord

<$15	*$15–19*	*$20–29*	*>$29*
mechanical-faller grapple-skidder	crawler	horse	mini-tractor
	cable skidder	cable yarder	cable yarder-plus-swing operation

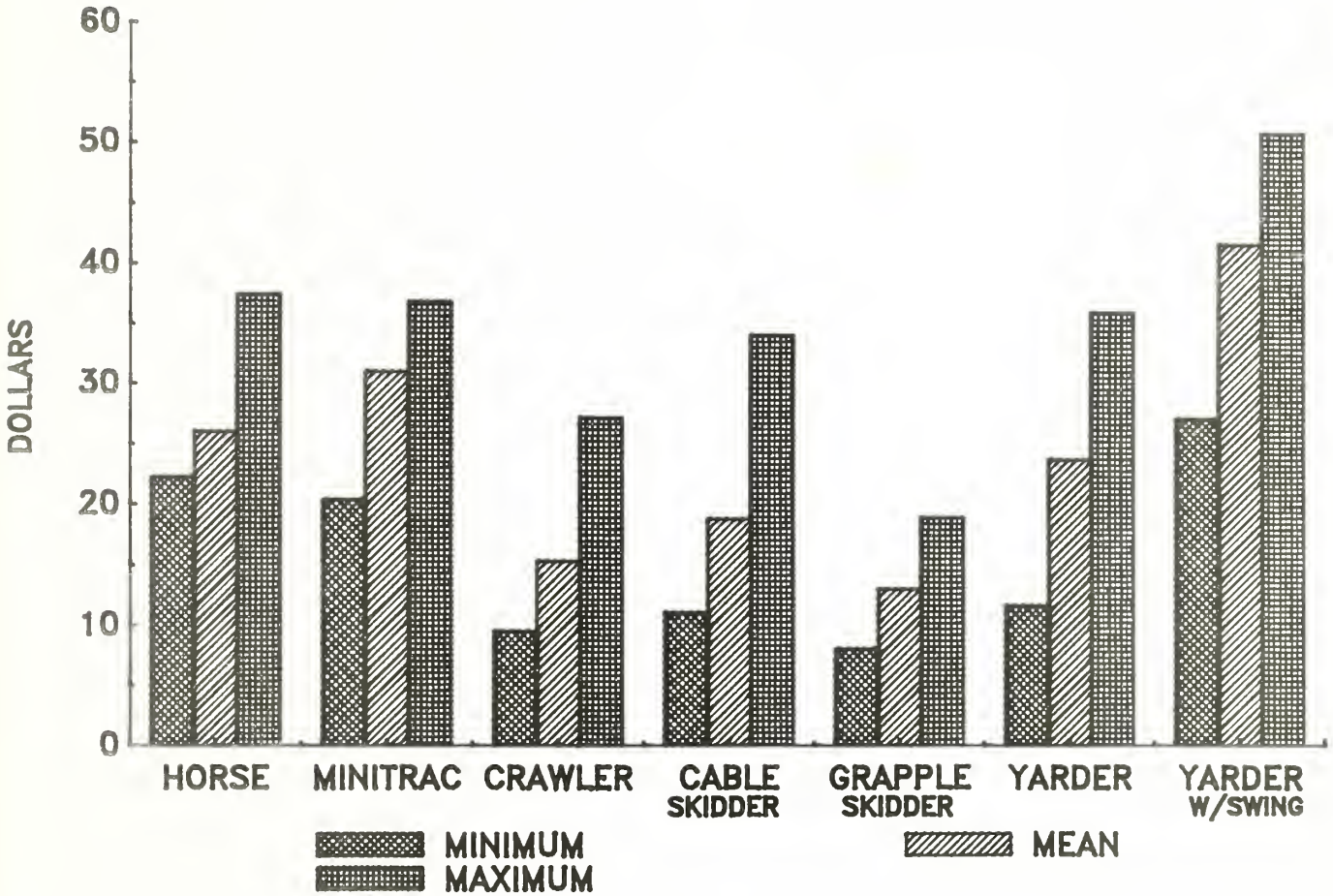

Figure 6.—Logging system cost per cord

Technical Factors Affecting Skidding and Yarding Operations

Although logging system productivity and costs are important considerations in determining the type of system to be used, technical factors may supersede these considerations. Important ones are terrain, environmental considerations, size of tract, type of cut, mean stand diameter, load capacity, skidding or yarding distance, and contract requirements. The effects of these factors on the suitability and economics of the six different logging systems are discussed in this section.

Terrain. Tractor and skidder logging systems are severely handicapped when skidding uphill on slopes in excess of 10 percent (for each 1 percent of adverse grade, maximum payload volume decreases by 2.5 percent). For this reason, ground skidding is preferably done downhill to truck roads located in the valleys. On the other hand, most cable systems are rigged to yard uphill to truck roads located on the ridges or contours (Sundberg 1976).

In addition to steepness of terrain, ground roughness and tractive capacity of soils affect the choice of logging method. Depending on the degree of these conditions, horses, tractors, and skidders can operate on a range of slopes as shown in Appendix, Table 7. Where slopes are excessively steep or rough, skid roads must be built for these systems to be used, and this increases costs. When the terrain is too steep and rough for ground skidding, cable yarding systems are to be preferred.

Environmental issues. Soil erosion and sedimentation are the most serious environmental problems associated with timber harvesting. Patric (1978) states that the "soil erosion hazard is increased most when logging is conducted on steep slopes, in wet soils, and along streams. Highest rates of erosion usually occur on logging roads and skid trails."

Section 208 of the Federal Water Pollution Control Act of 1972 requires the control of nonpoint sources of water pollution from forestry activities, including logging. The most direct approach for reducing soil erosion on timbered areas is to build as few roads as possible and to exercise all recommended guidelines for proper road construction, including erosion-control measures and revegetation after logging (Patric 1978).

Selection of logging equipment and preplanning of road layouts affect the amount of area in roads and trails exposed to erosion. In mountainous terrain, wheeled skidders are noted for the dense road network needed to move logs to landings. An estimate of timber acreage logged per mile of road built in the central Appalachians was reported by Kochenderfer and Wendel (1978). Skyline yarders, for example, create the least disturbance in the forest. They can log about 80 acres per mile of road constructed. For jammers the figure is about 31 acres, and for skidders, about 20 acres.

Ground skidding coupled with downhill logging results in more area disturbed and greater chance of erosion because the pattern of skid trails and roads tends to be fan-shaped with the apex at the bottom. Thus, water flows are concentrated and accelerated in their downhill movement. The opposite tends to be true with uphill logging methods, and they are preferable for that reason. However, one must consider the cost of building haul roads at midslope and ridgetop locations to accommodate these uphill logging systems.

Size of tract. Too big or too small a tract of timber can limit a contractor's choice of logging systems. Timber contract termination dates set the time frame for harvest completion. On large tracts of timber, the obligation to meet the completion date more or less restricts the choice of logging systems to one of the higher production systems. On the other hand, tracts smaller than 30 to 40 acres are often considered too small for economic operation by whole-tree chipping contractors because moving in a big spread of equipment is too costly for the harvestable volume.

Type of cut. Forest stands are subject to two principal kinds of cutting: partial cuttings and clearcuttings. Thinnings, timber stand improvement cuttings, and selection harvests—all partial cuts—are conducted in dense to well-stocked stands. In these stands, there is concern for potential damage to tree boles, tops, roots, and soil. Avoidance of stand damage often dictates that smaller, lighter, more maneuverable equipment be used. Where the terrain is relatively level, horses and mini-tractors are appropriate. On moderately steep to steep terrain, small crawlers, small skidders, or small cable yarders are necessary. With the ability to control tree felling and placement, feller-bunchers have advantages over chain saws for partial cuttings in immature stands. And, although safer to use, they require considerably larger investments.

Large rubber-tired skidders are better suited to clearcut harvests than to thinnings. A survey of 174 Minnesota loggers in 1979 found that the chain-saw felling/cable-skidder system was the most common type of operation reported in that state (Sinclair and Bolstad n.d.). It is also the most common in the central Appalachians. However, on both clearcut and partial cuts, skidders usually work from bulldozed skid roads on sites with slopes no greater than 40 percent (Gochenour and Hartman 1968).

Small crawler tractors are an attractive alternative to wheeled skidders for salvaging bug-killed lodgepole pine. Working on steep, sensitive terrain in the Rockies of British Columbia, the crawler had less skid trail impact than rubber-tired skidders and operated at lower costs than cable systems. Furthermore, operators found that the crawlers were more stable on steep slopes, were not dependent on a large tractor for trail construction and clearing, and were available a higher percentage of time than were skidders (McMorland 1980).

Mean stand diameter (MSD). Timber size has a direct bearing on equipment selection and productivity. For most logging systems, production rates are lower and costs are higher for small trees than for large trees (this is axiomatic within the logging industry). However, logging small timber can be profitable with systems employing faller-bunchers and grapple skidders. Berti (1984) found, for example, that faller-bunchers were essential in stands with harvestable trees averaging 10 inches or less in diameter at breast height (d.b.h.). In a 1979 study of Minnesota loggers, Bolstad and Sinclair (1981) reported that among 79 logging firms, mean productivity (in cords per man-hour) averaged 38 percent more for mechanical-faller/grapple-skidder systems than for chain-saw felling/cable-skidder systems.

Rubber-tired skidders and crawler tractors are available to handle all sizes of timber logged in the Northeast. Even the small crawler tractors reported in this paper handled loads comparable to those of cable skidders. Horses, mini-tractors, and small mobile yarders are more restricted in the size of logs they can handle, and this is directly reflected in their productivity.

Load capacity. Load capacity is an important factor in selecting skidding and yarding equipment; it is a function of machine configuration and horsepower. Coupled with skidding distance, load capacity pretty well determines the potential productivity of skidding and yarding machines. Actual productivity, however, is more a function of how well machine load capacity is utilized, and that is directly related to the size, density, and number of logs hooked up for each turn from stump to landing.

Data from some of the operations used in this study illustrate the point about load size per turn and machine load capacity. For example, Figure 7 shows that the average maximum load per turn for small (42 to 78 hp) crawler tractors exceeds the average maximum load per turn for both cable and grapple skidders having more horsepower than the crawlers! The specific crawler-tractor operation involved (Adams 1967) was a thinning in second-growth Douglas-fir with a mean stand d.b.h. of 13.4 inches. The trees were large, and the logs were sizable—0.24 cords per log. The 65-hp tractors on this operation averaged 10 logs per turn, for an average load size of 2.45 cords. The 50-hp tractors, on the same operation, averaged six logs per turn for an average load of 1.47 cords. These two west coast operations increased the overall average load size per turn for all small crawler tractors to 1.05 cords per turn—close to the average load size for cable and grapple skidders. However, the median load size per turn for all eight small crawler-tractor operations (Appendix, Table 4) was 0.74 cords per turn—more typical of load sizes one would expect for small crawler tractors logging second-growth eastern forests.

A similar example on the other extreme is the load size of the Bitterroot yarder working in Kentucky (Appendix, Table 6). Average loads of only 0.12 cords per turn were the result of the Bitterroot yarder's low mainline pull capacity (1,150 pounds). The only smaller load size in the data set was 0.09 cords per turn on a "logger's choice"[2] operation logged with a horse in West Virginia (Appendix, Table 1). In contrast to these examples of small loads per turn, the minimum load size on mechanical-faller/grapple-skidder operations was 0.59 cords, almost six times the minimum loads of the Bitterroot cable yarder and horse operations.

Skidding and yarding distance. On operable terrain, distance is the most important physical factor affecting skidding and yarding cycle times and, ultimately, productivity. On a particular logging chance, skidding and yarding distances can be good or bad depending on how much planning was done to provide the best combination of truck roads, skid roads, and landings for least total cost. Other factors to be considered in the planning process include volume and size of timber, skidding and yarding machines on hand or available, road construction feasibility, etc. Extensive determinations of this order, however, cannot be made on the basis of physical factors alone. They must include economic analyses based on the principles set forth by Matthews (1942).

As a result of such analyses, it may be found that a combination of skidding and yarding machines may be the best solution. For example, if long skidding distances are required it may be that skidders, in combination with crawler tractors for short hauls, may give the lowest overall skidding cost. Or on steep terrain, uphill logging with jammers on contour roads, in combination with small crawler tractors logging downhill, may be the best mix of equipment for maximum production and lowest cost. Grafton[3] points out that

[2] Logger cuts only trees yielding products he can sell.
[3] Personal communication.

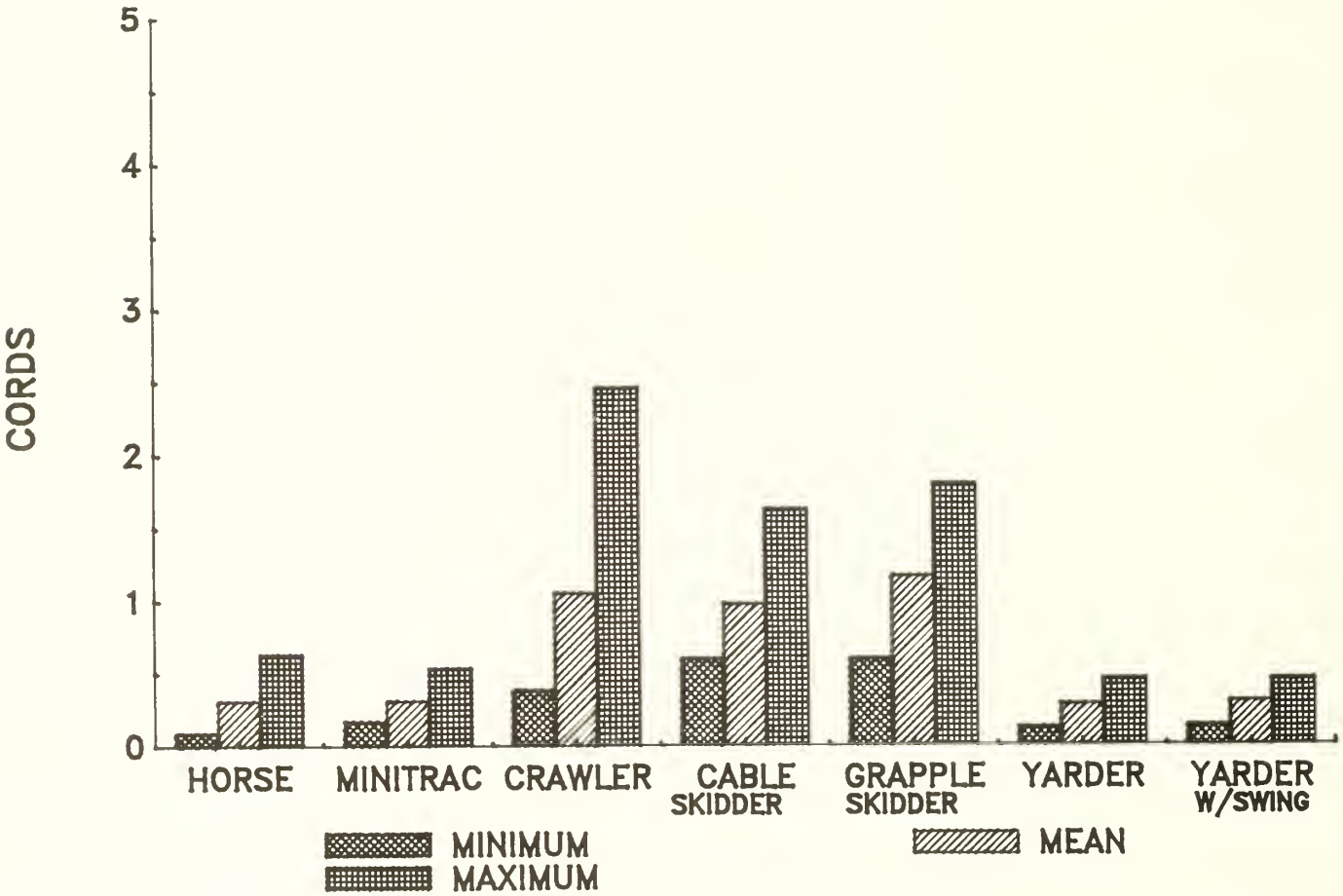

Figure 7.—Load size per turn

animals and skidders are a potentially useful combination. He reports that in Zimbabwe, bunching logs with oxen or mules works well in combination with rubber-tired skidders for the long skid distances.

The efficiency and productivity of a skidding method depend on a combination of factors—some of which (load size and terrain) have already been discussed. Travel speed and hooking methods are also important. They are the principal factors in how fast or slow cycle times are. Rubber-tired grapple skidders have the advantage of good travel speed plus fast hooking and unhooking. These features and others have made grapple and cable skidders the most popular skidding machines in the woods. However, there are harvesting situations where other machines are preferable. For example, in Holland, Leek and Schaafsma (1981) found that there is no need for skidders. Skidding can be done with horses or with agricultural tractors modified for logging. They recommend horses for thinning young stands where average skidding distances are 165 feet or less. Where skidding distances are greater, bunching with horses in combination with skidding by grapple-equipped tractors is recommended.

Choices among skidding and yarding machines are difficult to make on a subjective basis alone. Selection of machines for harvesting operations can begin with matching technical features to requirements of the job. But final selection should be based on a unit-cost analysis to determine break-even points among machines or combinations of machines for skidding distances, load size, and slopes that occur on the job.

Contract requirements. Many roundwood and chip purchasers prefer to deal solely with large-volume producers. This is more efficient and less costly for them than dealing with numerous small producers. Thus loggers seeking contracts with these firms are limited in their choice of logging systems. Out of necessity, they must choose one of the more costly high-production systems or forgo producing for these buyers.

The Effect of Economic Factors on System Selection

The six systems represent a broad range of required inputs in manpower, invested capital, and necessary operating funds. The farmer and son who own a team of horses, a set of harness, and a chain saw can be in the logging business with the purchase of log chains and fuel for the saw, and the hire of a trucker to haul logs to markets. Though production may be only 4 to 6 cords per day, if they can cover out-of-pocket costs and make wages for themselves, they are in business as loggers with a minimum outlay of capital.

The other extreme in the logging business today is the large whole-tree chip logging contractor outfitted with a faller-buncher, grapple skidders, a whole-tree chipper, several chip trailers and highway tractors, plus a couple of support vehicles, maintenance equipment, and spare parts. Investment in such an equipment spread can total $750,000 or more. Operating with a contract to deliver large tonnages (200 to 300 tons) of pulp chips to the mill each day, the contractor must produce wood at a cost below current prices ($19 to $20 per ton) or go out of business.

In the short run, a logging contractor must cover his variable costs of fuel, maintenance, and labor in order to stay in business. In the long run, the logger must also cover the fixed cost of his investment. The ability of a system to develop enough revenue to cover both fixed and variable costs is a necessary condition for equipment selection but is not the only condition governing equipment selection. Two other very important real-world economic questions are: (1) How much money can be obtained to purchase equipment, and what interest rate must be paid on this money? and (2) What degree of financial risk does the logger want to assume?

The availability of funds is a critical factor in purchasing logging equipment since many banks are reluctant to lend money to logging contractors. This means that loggers must use their own funds to purchase equipment or must borrow money from secondary processors or equipment companies at above-average interest rates. The combined effects of low accessibility of funds and high interest rates reduce the amount of money a logging contractor will or can borrow and thus decrease the number of state-of-the-art logging systems used. The less capital-intensive systems, such as cable skidders, small crawler tractors, or even horses, may be employed instead of grapple skidders and faller-bunchers, even though their average cost per cord is higher.

Owning logging equipment is risky because of the variability of timber markets and weather conditions. In idle periods or periods of reduced production, loggers who have borrowed money must still make payments, and loggers who invested their own money are losing the interest that money could earn in other investments. Risk emanates from capital or fixed costs rather than variable cost. Therefore, a logger may be more inclined to purchase a system with a relatively high variable cost and low fixed cost over a system with a high fixed cost and low variable cost.

The risk problem is associated with cash flow of incoming revenue versus outgoing costs. The degree of risk an individual is willing to take depends on his own personality and the amount of time his equipment can remain idle before he can no longer afford to make payments on it. The risk factor, like the availability of money, tends to encourage the purchase of less capital-intensive systems even though the operating cost of these systems may be higher.

Summary and Conclusions

Harvesting is a key and expensive process in the transformation of standing timber into wood products. From the analyses conducted in this study, we can draw several conclusions about the effects of harvesting on future stumpage and roundwood supplies and prices in the eastern forest regions, and on the realities logging contractors face in choosing and using harvesting systems.

With the exception of the cable yarder, the most efficient (lowest cost per unit of output) harvesting systems are the most capital-intensive systems. They are the systems with the highest fixed cost and the most risks for the contractors to finance and protect during unscheduled idle periods or periods of reduced production. The mechanical-faller/grapple-skidder system, the most capital intensive of current operating

systems, produces wood at the least cost per unit but is restricted by steep and rough terrain. The implication for stumpage and roundwood supplies and prices is that as long as timber is available on sites accessible to mechanical-faller/grapple-skidder logging, stumpage prices will be firm and roundwood prices moderate. As less timber is available on accessible lands, average stumpage prices will edge lower, harvesting costs will go up because of lower productivity of systems employed, and roundwood prices will rise as far as market strength permits.

Harvesting steep and environmentally sensitive lands will require the use of systems with lower productivity and higher unit costs. Stumpage prices for timber on these lands will be lower and contractors' revenues will be slimmer. If supplies of more accessible timber are sufficient to meet marketplace demands, less accessible timber will continue to go begging for a market.

The realities of the timber marketplace and harvesting systems' production and costs present a real dilemma for the logging contractor. To achieve high output and low unit costs, he's driven to use capital-intensive systems that are costly to finance and risky to keep solvent in the face of long, unexpected idle periods due to log-buying suspensions, mill closings, and so forth.

Loggers fortunate enough to have favorable long-term contracts and financing help from wood-using industries are those most able to employ capital-intensive, state-of-the-art logging systems. Loggers not so favorably connected must seek other options, such as more favorable financing arrangements, buying used equipment, and/or employing less costly systems. All logging contractors, regardless of system used, must strive for maximum production, while maintaining a tight rein on costs.

A paradox of timber economics exists at the interface between stumpage supplies and harvesting costs. Higher stumpage prices and increased supplies are possible at lower harvesting costs. Lower harvesting costs are achievable with current harvesting technology—but at a price. The price is higher cost, capital-intensive systems that are restricted in use by the inability of loggers to finance them at "reasonable" risk, and by forestlands too steep, rough, or environmentally sensitive for these systems to operate on. Much of the forestland in the Appalachian Mountains, for example, is too steep for the highly productive mechanical-faller/grapple-skidder system.

The challenge for future research as we see it is to develop financing arrangements that will allow loggers to invest in highly productive, capital-intensive systems with some protection against business failures due to the vagaries of weather, unstable markets, mill closures, and other causes of unscheduled idle periods. A second challenge for research is to develop state-of-the-art systems that will increase productivity and lower production costs on the steeper, rougher timberlands.

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Appendix

Table 1.—Data for six horse logging operations

Type of logging system	Ref. No.	Location	Terrain (% slope)	Type of cut	Species	Mean stand dia.	Roundwood product harvested	Skid./ yard. dist.	Load size per turn	Capital cost of equip.	Crew size	System cost per day	Production rate		Cost per cord
													per day	per man-day	
Draft horse:						*in*		*ft*	*cord*	*$*		*$*	*cord*	*cord*	*$*
single	(22)	WV	mountainous	thinning	oak hickory	NA	tree lengths	NA	NA	1681	2	152.64	6.67	3.33	22.88
team	(1)	NZ	0 to 50%	thinning	radiata pine	NA	tree lengths	NA	NA	3362	3	242.40	9.22	3.07	26.29
team	(7)	PA	5 to 30%	selection	oak cherry	NA	sawlogs	100 to 1000[a]	.50 to .75[a]	2752	2	160.32	3.75 to 5.00[a]	1.87 to 2.50[a]	32.06 to 42.75[a]
single	(22)	WV	mountainous	loggers choice	oak hickory	NA	tree lengths	169[b] 400	.09	1681	2	152.64	6.87 4.31[c]	3.43 2.81[c]	22.22 35.42[c]
single	(9)	VA & WV	mountainous	commercial clear cut	oak hickory	NA	tree lengths	NA	NA	1681	2	152.64	6.49	3.24	23.52
single	(11)	MT	22%[b]	clearcut	lodgepole pine	6.4	tree lengths	164[b] 400	.20	2752[d]	2	160.32	6.75 4.45[c]	3.37 2.23[c]	23.75 36.03[c]

[a] Range of values.
[b] Mean value.
[c] Value when skidding 400 feet.
[d] Two horses used alternately.

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Table 2.—Data for five mini-tractor logging operations

Type of logging system	Ref. No.	Location	Terrain (% slope)	Type of cut	Species	Mean stand dia.	Round-wood product harvested	Skid./ yard. dist.	Load size per turn	Capital cost of equip.	Crew size	System cost per day	Production rate		Cost per cord
													per day	per man-day	
Mini-tractor:						*in*		*ft*	*cord*	*$*		*$*	*cord*	*cord*	*$*
Pasquali 986 21 hp	(10)	ME	level but w/ undulating surface	thinning	spruce aspen	NA	tree lengths	400	.21	10989	2	171.04	4.78	2.39	35.78
Pasquali 991 24 hp	(23)	WV	mountainous	thinning	oak hickory	7.1	tree lengths	400	.17	11489	2	179.20	4.87	2.43	36.80
Pasquali 993 30 hp	(14)	NY	0 to 14% slopes w/ scattered rock outcrops	thinning	oak hickory	8.6	tree lengths	400	.25	14467	2	195.76	5.52	2.76	35.46
Forest Ant 12 hp	(14)	NY		thinning	oak hickory	8.4	tree lengths	400	.38	12710	2	182.56	6.88	3.44	26.53
Holder A60 48 hp	(14)	NY		thinning	oak hickory	8.6	tree lengths	400	.53	36177	2	271.84	13.36	6.68	20.35

Table 3.—Data for eight crawler-tractor logging operations

Type of logging system	Ref. No.	Location	Terrain (% slope)	Type of cut	Species	Mean stand dia.	Roundwood product harvested	Skid./ yard. dist.	Load size per turn	Capital cost of equip.	Crew size	System cost per day	Production rate		Cost per cord
													per day	per man-day	
Crawler tractor:						*in*		*ft*	*cord*	*$*		*$*	*cord*	*cord*	*$*
42 hp	(23)	WV	0 to 33%	thinning	oak hickory	7.1	tree lengths	351[a] 400	.39	43345	2	248.96	9.44 9.18[b]	4.72 4.59[b]	26.37 27.12[b]
50 hp	(2)	WA	0 to 40%	thinning	Douglas-fir	13.4	sawlogs long logs (28′–40′)	400	1.47	47375	2	260.96	27.46	13.73	9.50
65 hp	(2)	WA	0 to 40%	thinning	Douglas-fir	13.4	long logs (28′–40′)	400	2.45	51405	2	273.44	27.11	13.55	10.09
65 hp	(22)	WV	0 to 65%	thinning	cherry maple	NA	tree lengths	166[a] 400	.38	51405	2	273.44	19.01 11.76[b]	9.50 5.88[b]	14.38 23.25[b]
65 & 78 hp	(16)	Interior BC	0 to 80%	thinning	lodgepole pine	NA	tree lengths	400	1.32	57550[c]	2	288.96	24.77	12.38	11.66
78 hp	(22)	WV	0 to 37%	loggers choice	white pine	NA	tree lengths	217[a] 400	.79	63696	2	305.76	40.76 29.29[b]	20.38 14.64[b]	7.50 10.44[b]
42 hp	(22)	WV	0 to 23%	diameter limit	oak hickory	NA	tree lengths	235[a] 400	.56	43345	2	248.96	33.89 22.46[b]	16.94 11.23[b]	7.35 11.08[b]
42 hp	(9)	VA & WV	mountainous	commercial clear-cut	oak hickory	NA	tree lengths	NA	NA	43345	2	248.96	12.97	6.48	19.20

[a] Mean value.
[b] Value when skidding 400 feet.
[c] Price of 65 and 78 hp tractors averaged.

Table 4.—Data for ten cable-skidder logging operations

Type of logging system	Ref. No.	Location	Terrain (% slope)	Type of cut	Species	Mean stand dia.	Round-wood product harvested	Skid./ yard. dist.	Load size per turn	Capital cost of equip.	Crew size	System cost per day	Production rate		Cost per cord
													per day	per man-day	
						in		*ft*	*cord*	*$*		*$*	*cord*	*cord*	*$*
Cable skidder:															
90 hp	(8)	WV	mountain-ous	thinning	oak hickory	7.5	tree lengths	650[a] 1000	1.13	56730	2	343.20	30.80 20.02[b]	15.40 10.01[b]	11.15 17.14[b]
90 hp	(18)	WV	0 to 10%	thinning	cherry maple	6.0	tree lengths	500[a] 1000	1.53	56730	3	389.36	20.96 19.91[b]	6.99 6.64[b]	18.58 19.56[b]
90 hp	(22)	WV	0 to 36%	thinning	cherry maple	NA	tree lengths	450[a] 1000	.70	56730	3	390.24	21.98 16.43[b]	7.33 5.48[b]	17.75 23.75[b]
90 hp	(22)	WV	0 to 23%	thinning	cherry maple	NA	tree lengths	912[a] 1000	.72	56730	3	391.12	17.41 16.61[b]	5.80 5.53[b]	22.47 23.55[b]
90 hp	(22)	WV	0 to 45%	selection	oak hickory	NA	tree lengths	876[a] 1000	1.04	56730	2	334.00	19.83 19.68[b]	9.91 9.84[b]	16.84 16.97[b]
90 hp	(22)	WV	0 to 26%	diameter limit	oak hickory	NA	tree lengths	808[a] 1000	1.62	56730	2	334.00	36.98 30.22[b]	18.49 15.11[b]	9.03 11.05[b]
75 hp	(17)	MS	flat to hilly	commer-cial clearcut	S. pine & hard-woods	Total pine & hard-wood merch. & non-merch. range	tree lengths	800[a] 1000	NA	49410	2	298.96	24.94 22.85[b]	12.47 11.42[b]	11.99 13.08[b]
100 hp	(17)	MS	flat to hilly	commer-cial clearcut	"	2.5 to 13.0	tree lengths	800[a] 1000	NA	58255	2.5	375.42	29.09 27.02[b]	11.64 10.81[b]	12.91 13.89[b]
125 hp	(17)	MS	flat to hilly	commer-cial clearcut	"		tree lengths	800[a] 1000	NA	74420	3	458.00	33.25 30.65[b]	11.08 10.22[b]	13.77 14.94[b]
70 hp	(11)	MT	19%[a]	clearcut	lodgepole pine	6.4	tree lengths	254[a]	.59	49410	2	294.16	8.64	4.32	34.04

[a] Mean values.
[b] Values when skidding distance is 1000 feet.

Table 5.—Data for nine grapple-skidder logging operations

Type of logging system	Ref. No.	Location	Terrain (% slope)	Type of cut	Species	Mean stand dia.	Round-wood product harvested	Skid./ yard. dist.	Load size per turn	Capital cost of equip.	Crew size	System cost per day	Production rate		Cost per cord
													per day	per man-day	
						in		*ft*	*cord*	*$*		*$*	*cord*	*cord*	*$*
Grapple skidders: (plus mechan.-fallers)															
2-90 hp	(4)	NH	flat	thinning (in a plantation)	white pine	8.2	whole trees	725[a]	.59	184220	3	809.52	67.58	22.53	11.97
2-90 hp	(4)	NH	3 to 15%	"	red pine	7.3	whole trees	650[a]	.96	184220	3	809.52	72.90	24.30	11.07
2-120 hp	(4)	NH	flat	"	red pine	10.1	whole trees	1250[a]	1.01	277100	3	941.20	68.97	22.99	13.65
2-120 hp	(4)	NH	0 to 30%	salvage & thinning (nat. stand)	mixed hard-woods	7.4	whole trees	1500[a]	NA	277100	3	941.20	49.70	16.57	18.94
3-120 hp	(4)	NH	3 to 15% (rocky)	weed & thinning (nat. stand)	mixed northern hard-woods	7.8	whole trees	600[a]	1.25	382100	4	1259.44	71.72	23.91	17.56
2-120 hp	(4)	NH	flat	clearcut (nat. stand)	white pine	8.4	whole trees	400[a]	1.48	266686	3	897.60	111.52	37.17	8.05
144 hp	(6)	MI	flat	thinning	maple	9.2	whole trees	1518[a]	.89	183000	2	572.80	53.12	26.56	10.78
152 hp	(15)	MI	flat	thinning	maple elm	9.2	whole trees	321[a]	1.66	297354	2	854.18	95.82	62.38	8.91
152 & 110 hp	(12)	VT	5 to 25% but mostly 8 to 10%	thinning	northern hard-woods	9.2	whole trees	2657[a]	1.79	325710	3	861.84	52.63	17.54	16.38

[a] Mean skidding distance.

Table 6.—Data for nine cable-yarder logging operations

Type of logging system	Ref. No.	Location	Terrain (% slope)	Type of cut	Species	Mean stand dia.	Round-wood product harvested	Skid./ yard. dist.	Load size per turn	Capital cost of equip.	Crew size	System cost per day	Production rate		Cost per cord
													per day	per man-day	
						in		*ft*	*cord*	*$*		*$*	*cord*	*cord*	*$*
Cable yarders:															
A. Jammers															
Appalachian thinner	(5)	WV	40 to 70%	thinning	oak hickory	NA	tree lengths	134[a]	.28	63279	5	487.76	15.68[b]	3.14[b]	31.11[b]
Truck-mounted crane	(20)	WV	⩽ 35%	thinning	cherry maple	6.5	tree lengths	150[a]	.28	16277	3	250.64	21.52	7.17	11.65
B. Skyline yarders															
Vermont	(13)	VT	20 to 55%	thinning	northern hardwoods	8.5	tree lengths	377[a]	.22	35460	3	256.40	11.07	3.69	23.16
Skagit SJ2	(19)	OR	5 to 50%	thinning	Douglas-fir	12.8	log lengths	600[c]	.32	74693	6	610.88	16.96	2.83	36.02
Koller K300	(21)	VA	20 to 40%	commercial clearcut	oak	10 to 12	tree lengths	328[a]	.45	43200	4	397.84	22.67	5.67	17.55
Bitterroot	(3)	KY	mountainous	residue relogging	oak yellow-poplar	7.5	tree lengths & logs up to max. of .26 cd.	285[a]	.12	22080	3	275.68	11.89	3.96	23.19
C. Skyline yarders w/swing operations															
Skagit SJ2	(19)	OR	5 to 50%	thinning	Douglas-fir	12.8	tree lengths & whole trees	600[c]	.32	124103	7	842.32	17.93	2.56	46.98
Koller K300	(21)	VA	20 to 40%	commercial clearcut	oak	10 to 12	tree lengths	328[a]	.45	116620	4	615.52	22.67	4.53	27.15
Bitterroot	(3)	VA	15 to 40%	clearcut	oak hickory	NA	tree lengths & logs up to max. of .26 cd.	208[a]	.13	72875	6	592.80	11.64	1.94	50.93

[a] Mean yarding distance.
[b] Includes bucking and decking.
[c] Maximum yarding distance.

Table 7.—A selection guide for methods of log and tree extractions, given a range of terrain and soil conditions in temperate forests[a]

Terrain and Soil Conditions				Skidding and Yarding Extraction Methods[b]						
Steepness[c]	Ground roughness[d]	Relative traction capacity[e]	Slope direction	Horse	Mini-tractor	Crawler tractor	Cable skidder[f]	Grapple skidder[f]	Jammer[g]	Skyline yarder[g]
Slopes ⩽ 10%	smooth	good	uphill	X[h]	XX[i]	XX	XX	XX		
	to rough	bad	uphill	X	X	XX	XX	XX	XX	XX
	very rough	good	downhill	X		X	XX	XX	XX	XX
		bad	downhill	X		X	XX	XX	XX	XX
Slopes 11% to 50%	smooth	good	uphill		X < 15%	XX < 35%	XX < 25%	XX < 25%	XX	XX
	to	bad	uphill			X < 25%	XX < 20%	XX < 20%	XX	XX
	rough	good	downhill	XX < 30%	XX < 25%	XX	XX < 40%	XX < 30%		X
		bad	downhill	X < 30%	X < 15%	X	X < 40%	X < 30%		X
	very rough	good	uphill			X < 35%	X < 25%	X < 25%	XX	XX
		bad	uphill			X < 25%	X < 20%	X < 20%	XX	XX
		good	downhill	X < 30%		X	X < 40%	X < 25%		X
		bad	downhill			X	X < 40%			X
Slopes > 50%	smooth	good	uphill						XX	XX
	to	bad	uphill						XX	XX
	rough	good	downhill			XX < 60%				X
		bad	downhill							X
	very rough	good	uphill						XX	XX
		bad	uphill						XX	X
		good	downhill			X < 60%				X
		bad	downhill							

[a] Adapted from scheme by Rudolf Meyr in Sundberg 1976.
[b] When operating with normal loads.
[c] Refers to slopes longer than 150 feet; short slopes and pitches disregarded

[d] Refers to the occurrence or lack of obstacles more than 20 inches high, very rough includes numerous obstacles less than 10 feet apart

[e] "Good" refers to friction soils; "bad" to cohesive soils. Practical local experience, taking into account season and precipitation, is included in this classification

[f] Operating on adequately prepared skid roads.

[g] These methods are designed for steep, rough slopes. On flat group or moderate slopes, they are suitable only if ground skidding is impractical, uneconomical, or restricted for environmental reasons.

[h] X—Operations are suitable under stated conditions.
[i] XX—Operations are possible under stated conditions.

Sarles, Raymond L.; Luppold, William G. **Technoeconomic analysis of conventional logging systems operating from stump to landing.** Res. Pap. NE-577. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1986. 23 p.

Analyzes technical and economic factors for six conventional logging systems suitable for operation in eastern forests. Discusses financial risks and business implications for loggers investing in high-production, state-of-the-art logging systems. Provides logging contractors with information useful as a preliminary guide for selection of equipment and systems. Discusses economic effects of harvesting systems on future stumpage prices and longrun supply of roundwood material.

ODC 66

Keywords: Harvesting, logging, economics, systems analysis, equipment analysis

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Simulated Yields for Managed Northern Hardwood Stands

Dale S. Solomon
William B. Leak

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Abstract

Board-foot and cubic-foot yields developed with the forest growth model SIMTIM are presented for northern hardwood stands grown with and without management. SIMTIM has been modified to include more accurate growth rates by species, a new stocking chart, and yields that reflect species values and quality classes. Treatments range from no thinning to intensive quality product management over a range of sites.

Introduction

Yield tables that show merchantable stand volumes by age are basic to the practice of even-age timber management. They provide estimates of future volumes that are useful in regulating the yields from a forest, estimating rotation ages, and calculating management options.

Most yield tables are for fully stocked unmanaged stands. They were developed by measuring volumes in a series of well-stocked stands of different ages, and then graphing or regressing volume over age—usually for separate site classes. Although useful for extensive management, unmanaged stand yield tables cannot be used to estimate yields or rotations for managed or thinned stands.

In the United States, few forest stands have been managed long enough for the development of managed yield tables for any forest type. The best alternative is computer simulation models. A computer model was developed for northern hardwoods in New England that included substantial data on stocking and growth response (Solomon 1977a,b,c). From this model, managed yield tables have been developed that show thinning and harvest yields (board feet and cubic feet) by species and quality classes for three site index classes and five thinning regimes. The species composition of the stands used to predict yields depicts northern hardwoods as composed of less than 25 percent softwoods and approximately equal amounts of beech, birches, maples, and other associated hardwood species (Table 1). The merchantability limits were 4 inches inside bark for 5-inch-d.b.h. pulpwood and 6 or 8 inches inside bark at the smallest end for softwood and hardwood sawtimber, respectively. The log rule used was the International 1/4-inch saw kerf for 9.0-inch-d.b.h. softwood and 11.0-inch-d.b.h. hardwood sawlogs.

The Model

The original model was described for managed and unmanaged sapling (SIMSAP) and poletimber-sawtimber (SIMTIM) northern hardwood stands (Solomon 1977a). The overall framework of the model continues to be a distance-independent average-stand model, though numerous changes have been made. Input consists of site index, specifications on the thinning regime, and the stand characteristics of age, basal area, quadratic mean stand diameter, and percent of basal area by size, species, and quality. The model projects all of these stand characteristics by positioning the stand within the northern hardwood stocking chart (Fig. 1) and relating stand development to stocking. The lines in Figure 1 are developed from trees within the main crown canopy of northern hardwood stands. The main crown canopy is defined as all trees on the plot that are not overtopped or suppressed. The revised model incorporates additional growth data, growth rates by species, a new stocking guide, and conversion to board feet and cubic feet.

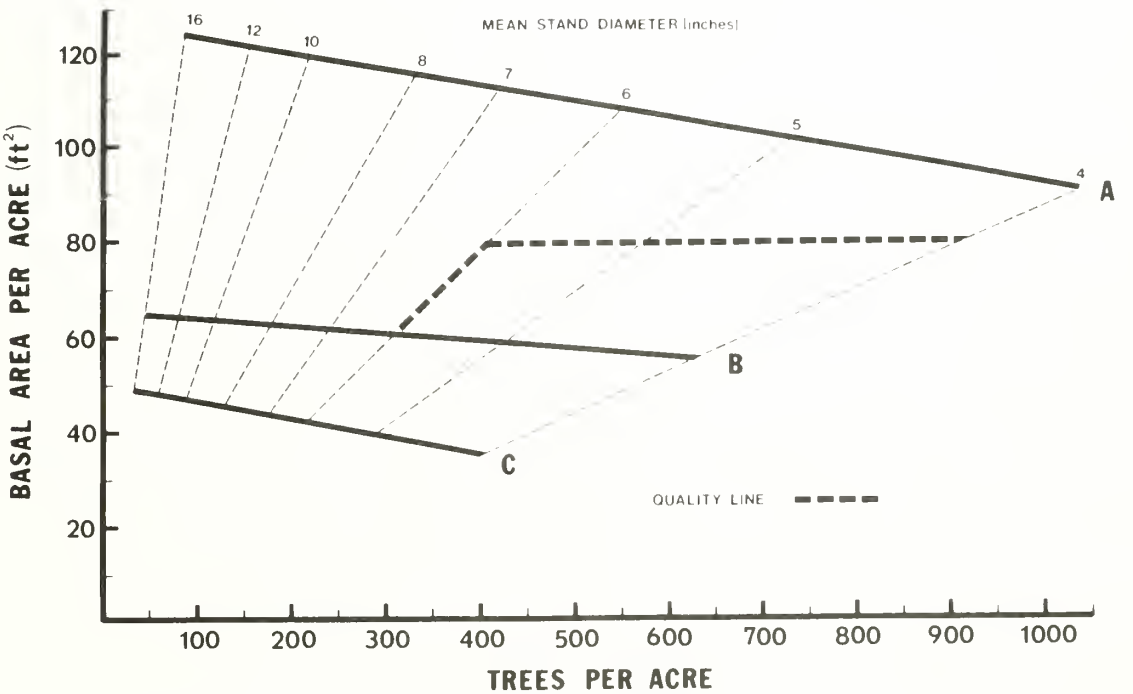

Figure 1.—Stocking chart for northern hardwoods is based on trees in the main crown canopy. The A line is average maximum stocking. The B line is recommended minimum stocking for adequate growth response per acre. The C line defines the minimum amount of acceptable growing stock for a manageable stand. The quality line defines the stocking measure in young stands for maintaining quality development.

The model SIMTIM is written in Fortran-77 and can be used interactively or by batch on any mainframe, microcomputer, or minicomputer that is MS/DOS compatible and has a minimum of 128K bytes of storage. Use of the model requires input for the following:

Job No—Indicates number of jobs or different sets of stand conditions to be used as input (1 to 999).

Title—Eighty characters used to separate jobs and identify management to be conducted on each stand.

Site—Site index of stand (site must be between 40 and 80).

POLEN—Average number of trees per acre in stand (25 to 1,500 trees).

BA—Basal area in square feet to nearest hundredth square foot (20 to 130 ft^2).

POLED—Quadratic mean stand diameter to nearest tenth of an inch (4 to 20 inches).

YEARS—Stand age in years.

SPQU—List species composition by quality classes of I, II, or III in following order: beech, yellow birch, sugar maple, red maple, paper birch-aspen, white ash, conifer, other. One quality class per line expressed to nearest tenth of a percent.

SPQUC—Order of removal of species from the quality class 3 x 8 matrix. Numbers from 1 to 24 are arranged in priority of removal.

THSPLT—Point in SPQUC for user to switch from complete species-quality class removal to proportional removal of remaining species quality classes. This maintains species composition and quality of species.

ITHIN—Regulates thinning by basal area in stocking chart:
- 0—No thinning
- 1—Thin when stand reaches A line
- 2—Thin when stand reaches user-specified basal area above B line. Enter amount of basal area above B line to begin thinning.

QTH—Thinning to quality line in Figure 1:
- 1—Thin to B line for all mean stand diameters.
- 2—Thin to 80 ft^2 up to 6-inch quadratic mean diameter, then thin to B line for stands with quadratic mean diameters greater than 6 inches.

PBMAX—Paper birch removal:
- 0—Paper birch mortality is removed between age 80 and 100. Removal is shown in thinnings after age 70.
- 1—User harvests paper birch.

THDBH—Quadratic mean diameter to the nearest tenth of an inch for thinning to begin.

XHARV—Quadratic mean diameter to the nearest tenth of an inch for final harvest.

XROT—Maximum age in years for final harvest.

IX—Any odd 9-digit random number used in mortality.

INTRVL—Reports given at specified intervals (years).

SAW—Percentage of sawtimber in stand.

Stand Growth

The amount of stocking, represented by the basal area, number of trees, and quadratic mean stand diameter, can be followed through time with the stocking chart (Fig. 1). The growth simulation within the model computes the number of trees per acre at both the A line and B line. The A line represents a fully stocked stand without any form of management. The B line is based on optimum stand growth from different northern hardwood growth studies. The number of trees at both the A line and the B line can be presented as a function of the natural logarithmic value of the quadratic mean stand diameter:

$$\text{A-line number of trees} = e^{(9.491 - 1.786 * \ln QMD)}$$
$$\text{B-line number of trees} = e^{(9.082 - 1.887 * \ln QMD)}$$

where
QMD = the diameter at breast height of the tree of average basal area.

The C line represents a managed stand with minimum level of acceptable growing stock (sawlog potential) that will grow to the B line in 10 years. The quality line maintains a higher level of basal-area stocking for a smaller quadratic mean diameter. Thinning a stand to the quality line provides clear bole form on younger, smaller high-quality species.

The stand growth components of accretion and ingrowth (ft^2/acre/year) can be expressed as:

$$\text{Accretion} = 2.153 + 0.005\,(\ln BA) - 0.0076\,(SAW)$$

$$\text{Ingrowth} = 3.200 - 0.643\,(\ln BA) - 0.0012\,(SAW)$$

where
BA = Residual basal area in square feet

SAW = Percentage of stand in sawtimber-size trees

Accretion = Dbh increment in basal area of trees present at the initial inventory, plus ingrowth accretion.

Ingrowth = Trees that grew larger than threshold size (5.0 inches) between inventories.

The R^2 values were 0.73 and 0.97; the standard errors of the mean were 0.0187 and 0.0138, respectively. These growth equations are based on information from managed stands of northern hardwoods (Marquis 1969; Solomon 1977b). The residual basal areas ranged from 20 to 100 ft^2 for these stands that were 20 to 80 years old. The percentage of sawtimber ranged from zero to 60. Stand mortality increases as the basal area and mean stand diameter increase.

Thus, as the stand grows from the B line to the A line, mortality increases. Our estimate of actual stand mortality is based on the assumption that mortality at minimum stocking (the B line) is zero, and that mortality of a stand above the B line is in some way proportional to its position between the A line and B line.

$$\text{Stand mortality} = \left(\frac{BA - BAB}{BAA + MF - BAB}\right)^{X} \cdot (GG - BAGA)$$

where

BA = basal area of stand

BAB = basal area at B line

BAA = basal area at A line

GG = gross growth

BAGA = annual net basal-area growth at A line

MF = mortality factor

X = a random exponent between 1 and 1.5.

When X = 1, mortality is computed in direct proportion to the position of the stand between the A line and B line. When X is greater than 1, the mortality rate increases as the A line is approached and passed. The mortality factor (MF) ranged from −2.5 for stands with basal areas of 60 ft^2 or less up to 2.0 for stands with 100 ft^2 or more.

Species Growth

Stand growth provides the forest manager with an estimate of the growth of northern hardwood stands. However, as species composition changes, the growth rate of any species may increase or decrease. Growth rates by species were computed and followed through the model as the user controls species composition (Marquis 1969; Solomon 1977b). Thus, stand growth, as computed from accretion, ingrowth, and mortality, is proportioned into species growth rate based on the residual basal area of the stand, size class, and percent of species composition. Therefore, changing species composition does not change stand growth, but changes the amount of growth allotted to individual species.

Yields

The growth rates of the combined species were compared to the stand growth and calculated as board-foot and cubic-foot yields at the time of harvest. Intermediate thinnings also are reported as a separate part of the total yield of the managed stand. Square feet of basal area is converted to both cubic feet and board feet based on the quadratic mean stand diameter (Leak 1980). Thus, the yields by species are based on the percentage of a species in the total basal area. The cubic feet per square foot of basal area give the total cubic feet; similarly, the board feet per square foot give the board feet. Then the board feet divided by the board feet/cubic feet ratio gives the amount of cubic feet in the sawtimber yields. By subtracting this amount from the total yield, we can estimate amount of cubic feet in pulp, cull, or extra sawtimber.

Thinning Options

The major species that made up the northern hardwood stand used to construct the model and presented in the yield tables were:

Yellow birch—*Betula alleghaniensis* Britton

Sugar maple—*Acer saccharum* Marsh.

White ash—*Fraxinus americana* L.

Paper birch—*Betula papyrifera* Marsh.

Other:

Red maple—*Acer rubrum* L.

Beech—*Fagus grandifolia* Ehrh.

Aspen—*Populus tremuloides* Michx.

Conifer

Hemlock—*Tsuga canadensis* (L.) Carr.

Red spruce—*Picea rubens* Sarg.

To provide forest managers with examples of yields from northern hardwood stands, five thinning regimes were modeled:

1. No thinning: The stands were allowed to develop naturally.
2. Quality-line thinning (Fig. 1): Up to 6 inches quadratic mean diameter; stands that reached the A line were thinned to 80 ft^2 of residual basal areas. The higher basal area in the smaller sized and younger

stand assured more height growth and increased natural pruning. Above 6 inches quadratic mean stand diameter, stands were thinned to B line whenever the basal area reached 30 ft^2 above the B line (approximately two-thirds of the distance from B line to A line).

3. 7-inch thinning: Stands were thinned to B line after mean stand diameter reached 7 inches and whenever the basal area exceeded the B line by 30 ft^2. The delay in the start of thinning to 7 inches quadratic mean stand diameter allowed for an increase in merchantable-size products prior to the start of thinning. A comparison to the more frequent thinning methods can be made.

4. 9-inch thinning: Stands were thinned to B line after quadratic mean stand diameter reached 9 inches and whenever the basal area exceeded the B line by 30 ft^2. The delay in the start of thinnings to 9 inches quadratic mean stand diameter allowed for an increase in merchantable size products prior to the start of thinnings. This thinning method might be used in remote areas or stands where frequent harvesting is not desirable.

5. A-line thinning: Stands were thinned once to 80 ft^2 of residual basal area, between 5 and 6 inches mean stand diameter. Above 6 inches mean diameter, the stands were thinned to B line whenever the basal area reached the A line.

All runs began at 4.0 inches mean stand diameter, 91 ft^2 of basal area per acre, and ages of 25, 30, and 35 years, respectively, for site indexes 70, 60, and 50 feet (site index for sugar maple at breast-height age 50). Stands were grown to 18.0 inches quadratic mean stand diameter.

Initial species composition varied by site index, based on available information on the relation of species to habitat (Leak 1978). The general form of the model recognizes three quality classes. Quality I stems are those with the potential to produce at least one sawlog now or in the future. Quality II stems are those with no sawlog potential. Quality III is cull. The proportion of basal area in potential quality I, II, and III stems was set at approximately 60, 30, and 10 percent, respectively (Table 1). To investigate yields from managed stands, quality II and III were combined. Also, to follow the yield by low- or high-value species, the high-value species of white ash, sugar maple, yellow birch, and paper birch were analyzed separately. The low-value species were grouped into a single category of "other".

Results

The yield tables in both gross board feet and gross cubic feet by site index and thinning method are in Tables 6–21. In this section we provide general interpretations about the influence of thinning on yield and quality; no deductions were made for defect or cull.

Cubic-foot production (thinned plus residual volumes) up to a quadratic mean diameter of 14 inches increased by approximately 30 to 50 percent by thinning compared to no thinning (Table 2). The amount of increase varied moderately with thinning intensity—the number of thinnings and the time of the first entry. By contrast, board-foot production up to 14 inches quadratic mean stand diameter was increased no more than 12 to 14 percent by thinning (Table 3). Almost no differences were observed among methods of management. One-third to one-half of the total cubic-foot or board-foot production comes from thinning.

The important differences in productivity among thinning regimes became evident when the time required to reach a given quadratic mean stand diameter was taken into account. Mean annual increment in cubic feet (volume divided by years) up to 14 inches mean stand diameter was increased by at least 100 percent by quality-line thinning compared to no thinning; mean annual board-foot increment increased by about 50 to 100 percent (Table 3). Annual board-foot increments were about 20 to 40 percent greater under quality-line thinning than under A-line thinning, and cubic-foot yields were 30 to 60 percent greater. The response to thinning, expressed in percent, was greater on the poorer sites.

Age of culmination of mean annual board-foot increment without thinning increased from about 100 to 120 years as site index decreased from 70 to 50 feet; the corresponding mean stand diameter at the point of culmination decreased from 14 to 10 inches as site index decreased (Table 4). The thinning treatments resulted in a slight to moderate increase in culmination age and diameter for site index 50. Thinning slightly decreased culmination age for site 70, but increased the corresponding culmination diameter by as much as 4 inches. On site 60, thinning increased culmination diameter slightly and, in most cases, caused a slight decrease in culmination age. Mean annual board-foot increment was increased through thinning by about 50 to 100 percent on site 50, and by 25 to 50 percent on site 70; there were intermediate gains on site 60.

Age of culmination of mean annual cubic-foot increment was less than 40 to 60 years under no thinning (Table 4). Culmination age and stand diameter were roughly doubled by thinning. Thinning increased mean annual increment by 40 to 60 percent, with the greatest increase on the better sites. However, low-intensity thinning methods had only a slight to moderate increase in mean annual increment. Culmination

ages for board-foot increment under any thinning method are only a little longer than those for cubic-foot increment.

Stand value is reflected by the proportions of high-value species and high-quality stems. On site index 50, the proportion of board-foot volume in high-value species and grade I stems changed from 11 percent without thinning to 14 percent with A-line thinning (Table 5). On sites 60 and 70, the proportion of high-value basal area ranged from about 50 percent without thinning to about 75 percent with thinning. Differences among sites were substantial, primarily because species composition varied between sites. Although thinning produced a substantial increase in high-value yield on sites 60 and 70, differences among thinning regimes were not large. However, consideration should be given to the differences in species composition in Table 1. More yellow birch was in the species composition on site index 60 and more white ash was present on site index 70.

Conclusion

SIMTIM was used to develop a series of managed yield tables for even-aged northern hardwood stands over a range of thinning methods and site indexes. SIMTIM provides estimates of board-foot and cubic-foot yields by species and quality.

Intensive thinning increased total mean annual yields by at least 100 percent for cubic-foot volumes, and by 50 to 100 percent for board-foot volumes. Thinning had little effect on rotation length (culmination of mean annual increment) for board-foot volume, but nearly doubled rotations for cubic-foot volume. Optimum rotations for intensively thinned stands ranged from about 80 to 90 years for cubic-foot production and 90 to 125 years for board-foot production on sites 70 to 50, respectively. Intensive thinning on sites 60 and 70 raised the proportion of quality I high-value species from about 50 to 75 percent.

The managed yield tables for northern hardwoods should prove useful to forest managers as well as those engaged in research on economic returns. An example of the program output is given in Table 21.

The computer program described in this publication is available on request with the understanding that the U.S. Department of Agriculture cannot assure its accuracy, completeness, reliability, or suitability for any other purpose than that reported. The recipient may not assert any proprietary rights thereto nor represent it to anyone as other than a Government-produced computer program. For cost information, please write: Northeastern Forest Experiment Station, USDA Building-University of Maine, Orono, Maine 04469.

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Table 1.—Initial species composition (at 4.0 inches mean d.b.h.) in percent of basal area, by site index and quality class

Site index	Quality class[a]	Beech	Yellow birch	Sugar maple	Red maple	Paper birch	White ash	Conifer	Other	All
50	I	27	9	2	11	10	0	2	0	61
	II	14	5	1	5	5	0	0	0	30
	III	4	1	0	2	1	0	0	1	9
60	I	7	23	22	1	5	1	0	0	59
	II	4	11	11	0	3	1	0	0	30
	III	1	4	4	0	1	0	0	1	11
70	I	6	6	23	0	6	17	1	0	59
	II	3	3	11	1	3	9	0	0	30
	III	1	1	4	0	1	3	0	1	11

[a] Quality class I: sawlog or veneer potential in at least one 16-foot log; class II: no veneer or sawlog potential; class III: cull trees.

Table 2.—Residual and cumulative thinned volume per acre at 14 inches quadratic mean diameter (QMD), by thinning method and site index

Thinning		Begin QMD	Site index 50			Site index 60			Site index 70		
Method	No.		Thinned	Residual	All	Thinned	Residual	All	Thinned	Residual	All
						Ft^3/acre					
No thinning	0	—	—	2595	2595	—	3102	3102	—	3579	3579
Quality line	5	5.2	2128	1738	3866	2602	2011	4613	3019	2389	5408
7 inch	3	7.1	1633	1990	3623	1959	2369	4328	2330	2654	4984
9 inch	2	9.1	1284	2069	3353	1570	2374	3944	1766	2839	4605
A line	2	5.2	1880	1485	3365	1002	2991	3993	1156	3459	4615
						Board feet/acre					
No thinning	0	—	—	10959	10959	—	13048	13048	—	15079	15079
Quality line	5	5.2	4596	7502	12098	5633	8449	14082	6650	10139	16789
7 inch	3	7.1	3928	8538	12466	4660	9957	14617	5790	11251	17041
9 inch	2	9.1	3630	8789	12419	4517	9977	14494	5044	12025	17069
A line	2	5.2	5572	6464	12036	1527	12573	14100	1722	14620	16342

Table 3.—Years to reach 14 inches quadratic mean diameter and mean annual increment per acre, by thinning method and site index

Thinning method	Site index 50			Site index 60			Site index 70		
	Years	Board feet	Cubic feet	Years	Board feet	Cubic feet	Years	Board feet	Cubic feet
No thinning	236	46.4	11.0	157	83.1	19.8	102	147.8	35.1
Quality line	124	97.6	31.2	95	148.2	48.6	77	218.0	70.2
7 inch	137	91.0	26.4	101	144.7	42.9	80	213.0	62.3
9 inch	154	80.6	21.8	110	131.8	35.9	86	198.5	53.5
A line	181	66.5	18.6	119	118.5	33.6	88	185.7	52.4

Table 4.—Approximate[a] mean annual increment (MAI) to the point of culmination in age and quadratic mean diameter (QMD)

Thinning method	Site 50			Site 60			Site 70		
		Culmination			Culmination			Culmination	
	MAI	Age	QMD	MAI	Age	QMD	MAI	Age	QMD
	Ft³	*Years*	*Inches*	*Ft³*	*Years*	*Inches*	*Ft³*	*Years*	*Inches*
No thinning	21.8	< 59	< 6	31.6	< 49	< 6	44.4	< 41	< 6
Quality line	30.9	105	12	48.6	95	14	70.2	77	14
7 inch	25.2	119	12	42.9	101	14	62.3	80	14
9 inch	21.0	129	12	35.9	110	14	53.5	86	14
A line	24.3	98	10	36.5	78	10	53.9	75	12
	Board feet	*Years*	*Inches*	*Board Feet*	*Years*	*Inches*	*Board feet*	*Years*	*Inches*
No thinning	46.3	120	10	85.8	114	12	147.8	102	14
Quality line	97.6	124	14	148.2	95	14	227.3	92	18
7 inch	91.0	137	14	144.7	101	14	216.8	89	16
9 inch	80.6	154	14	131.8	110	14	198.5	86	14
A line	67.5	133	12	118.5	119	14	185.7	88	14

[a] Culmination determined directly from yield tables in this publication, without interpolation between age or diameter intervals; culmination is defined as the point where MAI is within about 1 ft^3 or 7 board feet of maximum.

Table 5.—Percentage board-foot volume (thinned plus standing volume) at a quadratic mean diameter of 14 inches in high-value and low-value species[a] and in quality classes I and II[b], by thinning method and site index

Thinning method	Site index 50						Site index 60						Site index 70					
	High value			Low value			High value			Low value			High value			Low value		
	I	II	All	I	II	All	I	II	All	I	II	All	I	II	All	I	II	All
No thinning	11	7	18	52	30	82	49	34	83	10	7	17	50	34	84	10	6	16
Quality line	12	—	12	88	—	88	83	—	83	17	—	17	79	—	79	21	—	21
7 inch	13	2	15	82	3	85	77	5	82	17	1	18	75	5	80	19	1	20
9 inch	14	3	17	73	10	83	71	12	83	15	2	17	68	12	80	18	2	20
A line	14	4	18	80	2	82	76	8	84	16	—	16	75	8	83	17	—	17

[a] High-value species: white ash, sugar maple, yellow birch, and paper birch; low-value species: beech, red maple, conifers, and miscellaneous.

[b] Quality class I: sawlog or veneer potential in at least one 16-foot log; class II: no sawlog or veneer potential (includes cull trees).

Table 6.—Residual volumes per acre, by species and quality class (I and II), for no thinning and site index 50

Mean d.b.h. (inches)	Age	Residual basal area	White ash		Sugar maple		Yellow birch		Paper birch		Other		Combined		
			I	II	I	II	I	II	I	II	I	II	I	II	All
	Years	*Ft²*	*Ft³/acre*												
4	35	91	—	—	—	—	—	—	—	—	—	—	—	—	—
6	59	103	—	—	20	10	95	64	177	106	506	311	798	491	1289
8	83	107	—	—	24	12	116	77	201	121	664	391	1005	601	1606
10	120	111	—	—	36	19	174	116	—	—	1000	589	1210	724	1934
12	182	114	—	—	43	21	204	136	—	—	1176	692	1423	849	2272
14	236	116	—	—	49	24	234	156	—	—	1342	790	1625	970	2595
16	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
18	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
			Board feet/acre												
4	35	91	—	—	—	—	—	—	—	—	—	—	—	—	—
6	59	103	—	—	—	—	—	—	—	—	—	—	—	—	—
8	83	107	—	—	45	22	213	141	370	222	1251	719	1879	1104	2983
10	120	111	—	—	104	52	496	331	—	—	2892	1679	3492	2062	5554
12	182	114	—	—	156	78	739	493	—	—	4293	2500	5188	3071	8259
14	236	116	—	—	207	104	981	654	—	—	5692	3321	6880	4079	10959
16	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
18	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Table 7.—Residual volumes per acre, by species and quality class (I and II) for no thinning and site index 60

Mean d.b.h. (inches)	Age	Residual basal area	White ash		Sugar maple		Yellow birch		Paper birch		Other		Combined		
			I	II	I	II	I	II	I	II	I	II	I	II	All
	Years	*Ft²*	*Ft³/acre*												
4	30	91	—	—	—	—	—	—	—	—	—	—	—	—	—
6	49	102	21	21	303	207	340	222	120	96	124	93	908	639	1547
8	67	107	27	27	350	238	401	261	193	154	156	117	1127	797	1924
10	87	110	34	34	451	307	517	338	153	123	202	152	1357	954	2311
12	114	113	45	45	598	408	687	448	—	—	268	201	1598	1102	2700
14	157	116	51	51	687	469	789	515	—	—	309	231	1836	1266	3102
16	196	118	52	52	699	477	802	523	—	—	313	236	1866	1288	3154
18	230	119	53	53	707	482	812	530	—	—	317	238	1889	1303	3192
			Board feet/acre												
4	30	91	—	—	—	—	—	—	—	—	—	—	—	—	—
6	49	102	—	—	—	—	—	—	—	—	—	—	—	—	—
8	67	107	49	49	646	441	742	484	357	285	289	218	2083	1477	3560
10	87	110	98	98	1295	883	1487	969	441	352	580	437	3901	2739	6640
12	114	113	163	163	2167	1478	2488	1622	—	—	971	731	5789	3994	9783
14	157	116	218	218	2890	1970	3318	2164	—	—	1295	975	7721	5327	13048
16	196	118	221	221	2936	2002	3371	2198	—	—	1317	991	7845	5412	13257
18	230	119	224	224	2972	2026	3412	2225	—	—	1332	1003	7940	5478	13418

Table 8.—Residual volumes per acre, by species and quality class (I and II) for no thinning and site index 70

Mean d.b.h. (inches)	Age	Residual basal area	White ash		Sugar maple		Yellow birch		Paper birch		Other		Combined		
			I	II	I	II	I	II	I	II	I	II	I	II	All
	Years	*Ft²*	*Ft³/acre*												
4	25	91	—	—	—	—	—	—	—	—	—	—	—	—	—
6	41	103	372	263	334	218	95	63	150	100	122	104	1073	748	1821
8	55	107	480	339	358	234	107	71	232	154	156	123	1333	921	2254
10	69	110	553	391	398	259	120	80	320	213	200	141	1591	1084	2675
12	85	112	689	486	495	323	149	99	284	189	254	176	1871	1273	3144
14	102	114	923	652	663	432	200	133	—	—	340	236	2126	1453	3579
16	127	117	942	665	677	442	204	136	—	—	347	241	2170	1484	3654
18	157	119	959	677	688	449	207	138	—	—	353	245	2207	1509	3716
			Board feet/acre												
4	25	91	—	—	—	—	—	—	—	—	—	—	—	—	—
6	41	103	—	—	—	—	—	—	—	—	—	—	—	—	—
8	55	107	904	638	674	440	201	134	436	291	309	231	2524	1734	4258
10	69	110	1575	1112	1131	738	340	227	910	607	590	402	4546	3086	7632
12	85	112	2506	1769	1800	1174	542	361	1032	688	949	640	6829	4632	11461
14	102	114	3881	2740	2787	1818	839	559	—	—	1464	991	8971	6108	15079
16	127	117	3961	2796	2845	1856	856	571	—	—	1494	1011	9156	6234	15390
18	157	119	4029	2844	2894	1888	871	581	—	—	1520	1028	9314	6341	15655

Table 9.—Residual and cumulative thinned[a] volume per acre for quality-line thinning and site index 50

Mean d.b.h. (inches)	Age	Residual basal area	White ash				Sugar maple				Yellow birch				Paper birch				Other				Combined					
			Thin		Residual		Thin		Residual		Thin		Residual		Thin		Residual		Thin		Residual		Thin			Residual		
			I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	All	I	II	All
	Years	*Ft²*	----------												*Ft³/acre*													
4	35	91	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	57	99	—	—	—	—	—	—	23	11	—	10	106	59	—	14	184	92	—	202	581	102	—	226	226	894	264	1158
8	74	65	—	—	—	—	13	11	23	—	54	69	97	—	99	106	182	—	356	304	694	—	522	490	1012	996	—	996
10	89	92	—	—	—	—	13	11	36	—	54	69	143	—	99	106	135	—	356	304	1294	—	522	490	1012	1608	—	1608
12	105	87	—	—	—	—	24	11	36	—	99	69	140	—	142	106	—	—	765	304	1549	—	1030	490	1520	1725	—	1725
14	124	78	—	—	—	—	37	11	34	—	149	69	131	—	142	106	—	—	1310	304	1573	—	1638	490	2128	1738	—	1738
16	147	66	—	—	—	—	50	11	29	—	199	69	111	—	142	106	—	—	1905	304	1329	—	2296	490	2786	1469	—	1469
18	162	82	—	—	—	—	50	11	36	—	199	69	139	—	142	106	—	—	1905	304	1659	—	2296	490	2786	1834	—	1834
			----------												*Board feet/acre*													
4	35	91	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	57	99	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
8	74	65	—	—	—	—	17	—	44	—	71	—	188	—	133	—	354	—	505	—	1386	—	726	—	726	1972	—	1972
10	89	92	—	—	—	—	17	—	104	—	71	—	407	—	133	—	384	—	505	—	3799	—	726	—	726	4694	—	4694
12	105	87	—	—	—	—	50	—	129	—	200	—	506	—	254	—	—	—	1707	—	5774	—	2211	—	2211	6409	—	6409
14	124	78	—	—	—	—	98	—	141	—	388	—	552	—	254	—	—	—	3856	—	6809	—	4596	—	4596	7502	—	7502
16	147	66	—	—	—	—	151	—	119	—	597	—	466	—	254	—	—	—	6433	—	5755	—	7435	—	7435	6340	—	6340
18	162	82	—	—	—	—	151	—	149	—	597	—	582	—	254	—	—	—	6433	—	7181	—	7435	—	7435	7912	—	7912

[a] Six thinnings at mean d.b.h. 5.2, 6.0, 7.8, 10.0, 12.7, and 15.9.

Table 10.—Residual and cumulative thinned[a] volume per acre for quality-line thinning and site index 60

Mean d.b.h. (inches)	Age	Residual basal area	White ash				Sugar maple				Yellow birch				Paper birch				Other				Combined					
			Thin		Residual		Thin		Residual		Thin		Residual		Thin		Residual		Thin		Residual		Thin			Residual		
			I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	All	I	II	All
	Years	*Ft²*	*Ft³/acre*																									
4	30	91	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	48	93	—	—	24	24	—	51	353	177	—	117	386	106	—	18	129	77	—	83	142	—	—	269	269	1034	384	1418
8	61	66	15	24	32	—	201	228	406	—	212	222	421	—	78	95	158	—	85	83	172	—	591	652	1243	1189	—	1189
10	72	91	15	24	53	—	201	228	668	—	212	222	643	—	78	95	254	—	85	83	294	—	591	652	1243	1912	—	1912
12	83	85	33	24	58	—	414	228	745	—	417	222	679	—	159	95	222	—	179	83	335	—	1202	652	1854	2039	—	2039
14	95	75	55	24	63	—	701	228	811	—	678	222	738	—	207	95	33	—	309	83	366	—	1950	652	2602	2011	—	2011
16	107	91	55	24	79	—	701	228	1004	—	678	222	913	—	207	95	—	—	309	83	453	—	1950	652	2602	2449	—	2449
18	119	78	81	24	67	—	1026	228	855	—	973	222	777	—	207	95	—	—	455	83	386	—	2742	652	3394	2085	—	2085
			Board feet/acre																									
4	30	91	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	48	93	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
8	61	66	23	—	58	—	305	—	756	—	319	—	783	—	119	—	293	—	129	—	321	—	895	—	895	2211	—	2211
10	72	91	23	—	153	—	305	—	1910	—	319	—	1840	—	119	—	728	—	129	—	840	—	895	—	895	5471	—	5471
12	83	85	73	—	213	—	927	—	2695	—	918	—	2454	—	357	—	802	—	405	—	1211	—	2680	—	2680	7375	—	7375
14	95	75	162	—	268	—	2060	—	3408	—	1950	—	3100	—	546	—	135	—	915	—	1538	—	5633	—	5633	8449	—	8449
16	107	91	162	—	332	—	2060	—	4217	—	1950	—	3836	—	546	—	—	—	915	—	1904	—	5633	—	5633	10289	—	10289
18	119	78	269	—	283	—	3424	—	3590	—	3191	—	3266	—	546	—	—	—	1530	—	1621	—	8960	—	8960	8760	—	8760

[a] Six thinnings at mean d.b.h. 5.2, 6.1, 7.8, 10.2, 13.1, and 16.5.

Table 11.—Residual and cumulative thinned[a] volume per acre for quality-line thinning and site index 70

Mean d.b.h. (inches)	Age	Residual basal area	White ash				Sugar maple				Yellow birch				Paper birch				Other				Combined					
			Thin		Residual		Thin		Residual		Thin		Residual		Thin		Residual		Thin		Residual		Thin			Residual		
			I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	All	I	II	All
	Years	*Ft²*	*Ft³/acre*																									
4	25	91	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	40	93	—	55	422	223	—	87	383	146	—	59	106	—	—	20	159	79	—	94	139	—	—	315	315	1209	448	1657
8	50	67	251	278	538	—	197	233	410	—	54	59	110	—	91	99	190	—	83	94	178	—	676	763	1439	1426	—	1426
10	59	91	251	278	862	—	197	233	594	—	54	59	154	—	91	99	293	—	83	94	319	—	676	763	1439	2222	—	2222
12	68	85	526	278	922	—	385	233	607	—	103	59	148	—	185	99	295	—	186	94	423	—	1385	763	2148	2395	—	2395
14	77	76	853	278	873	—	601	233	580	—	155	59	134	—	290	99	270	—	357	94	532	—	2256	763	3019	2389	—	2389
16	85	92	853	278	1021	—	601	233	683	—	155	59	157	—	290	99	230	—	357	94	777	—	2256	763	3019	2868	—	2868
18	92	78	1173	278	861	—	815	233	578	—	204	59	133	—	352	99	64	—	608	94	810	—	3152	763	3915	2446	—	2446
			Board feet/acre																									
4	25	91	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	40	93	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
8	50	67	399	—	1033	—	309	—	787	—	84	—	212	—	144	—	366	—	139	—	362	—	1075	—	1075	2760	—	2760
10	59	91	399	—	2466	—	309	—	1700	—	84	—	442	—	144	—	837	—	139	—	955	—	1075	—	1075	6400	—	6400
12	68	85	1207	—	3365	—	862	—	2216	—	227	—	541	—	419	—	1075	—	456	—	1610	—	3171	—	3171	8807	—	8807
14	77	76	2504	—	3668	—	1717	—	2439	—	433	—	565	—	835	—	1136	—	1161	—	2331	—	6650	—	6650	10139	—	10139
16	85	92	2504	—	4289	—	1717	—	2872	—	433	—	660	—	835	—	967	—	1161	—	3415	—	6650	—	6650	12203	—	12203
18	92	78	3849	—	3619	—	2618	—	2430	—	640	—	557	—	1095	—	269	—	2263	—	3571	—	10465	—	10465	10446	—	10446

[a] Six thinnings at mean d.b.h. 5.2, 6.2, 7.9, 10.2, 13.1, and 16.6.

Table 12.—Residual and cumulative thinned[a] volume per acre for 7-inch thinning and site index 50

Mean d.b.h. (inches)	Age	Residual basal area	White ash				Sugar maple				Yellow birch				Paper birch				Other				Combined					
			Thin		Residual		Thin		Residual		Thin		Residual		Thin		Residual		Thin		Residual		Thin			Residual		
			I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	All	I	II	All
	Years	*Ft²*	*Ft³/acre*																									
4	35	91	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	59	103	—	—	—	—	—	—	20	10	—	—	95	64	—	—	177	106	—	—	506	311	—	—	—	798	491	1289
8	78	78	—	—	—	—	1	11	27	—	4	67	120	—	8	129	254	—	21	340	773	—	34	547	581	1174	—	1174
10	95	75	—	—	—	—	12	11	33	—	55	67	143	—	66	128	38	—	378	340	1102	—	511	546	1057	1316	—	1316
12	119	64	—	—	—	—	26	11	33	—	116	67	145	—	66	128	—	—	878	340	1186	—	1086	546	1632	1364	—	1364
14	137	89	—	—	—	—	26	11	45	—	116	67	199	—	66	128	—	—	879	340	1746	—	1087	546	1633	1990	—	1990
16	157	78	—	—	—	—	41	11	39	—	181	67	174	—	66	128	—	—	1457	340	1528	—	1745	546	2291	1741	—	1741
18	177	94	—	—	—	—	41	11	49	—	181	67	209	—	66	128	—	—	1457	340	1829	—	1745	546	2291	2087	—	2087
			Board feet/acre																									
4	35	91	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	59	103	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
8	78	78	—	—	—	—	1	13	49	—	5	82	219	—	10	159	465	—	27	418	1458	—	43	672	715	2191	—	2191
10	95	75	—	—	—	—	29	13	93	—	128	82	409	—	151	159	107	—	908	419	3244	—	1216	673	1889	3853	—	3853
12	119	64	—	—	—	—	76	13	121	—	339	82	532	—	151	159	—	—	2689	419	4478	—	3255	673	3928	5131	—	5131
14	137	89	—	—	—	—	76	13	190	—	339	82	836	—	151	159	—	—	2689	419	7512	—	3255	673	3928	8538	—	8538
16	157	78	—	—	—	—	139	13	166	—	616	82	732	—	151	159	—	—	5176	419	6573	—	6082	673	6755	7471	—	7471
18	177	94	—	—	—	—	139	13	199	—	616	82	876	—	151	159	—	—	5176	419	7869	—	6082	673	6755	8944	—	8944

[a] Four thinnings at mean d.b.h. 7.1, 9.1, 11.6, and 14.6.

Table 13.—Residual and cumulative thinned[a] volume per acre for 7-inch thinning and site index 60

Mean d.b.h. (inches)	Residual basal area	White ash				Sugar maple				Yellow birch				Paper birch				Other				Combined					
		Thin		Residual		Thin		Residual		Thin		Residual		Thin		Residual		Thin		Residual		Thin			Residual		
Age		I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	All	I	II	All
Years	*Ft²*	*Ft³/acre*																									
4	91	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	102	—	—	21	21	—	—	303	207	—	—	340	222	—	—	120	96	—	—	124	93	—	—	—	908	639	1547
8	79	—	18	36	9	—	222	464	—	—	243	506	—	—	125	219	—	—	105	203	—	—	713	713	1428	9	1437
10	76	14	29	42	—	178	222	537	—	188	243	537	—	84	125	238	—	80	105	243	—	544	724	1268	1597	—	1597
12	67	33	29	46	—	426	222	602	—	432	243	595	—	151	125	105	—	193	105	276	—	1235	724	1959	1624	—	1624
14	88	33	29	72	—	426	222	939	—	432	243	924	—	151	125	—	—	193	105	434	—	1235	724	1959	2369	—	2369
16	76	56	29	62	—	737	222	812	—	738	243	800	—	151	125	—	—	337	105	374	—	2019	724	2743	2048	—	2048
18	91	56	29	75	—	737	222	970	—	738	243	954	—	151	125	—	—	337	105	447	—	2019	724	2743	2446	—	2446
		Board feet/acre																									
4	91	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	102	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
8	79	—	22	69	17	—	272	885	—	—	297	965	—	—	153	416	—	—	129	387	—	—	873	873	2722	17	2739
10	76	34	50	120	—	435	272	1550	—	459	297	1550	—	206	153	684	—	195	130	700	—	1329	902	2231	4604	—	4604
12	67	101	50	170	—	1305	272	2227	—	1318	297	2202	—	440	153	392	—	594	130	1020	—	3758	902	4660	6011	—	6011
14	88	101	50	302	—	1305	272	3949	—	1318	297	3884	—	440	153	—	—	594	130	1822	—	3758	902	4660	9957	—	9957
16	76	201	50	261	—	2612	272	3415	—	2605	297	3359	—	440	153	—	—	1197	129	1575	—	7055	901	7956	8610	—	8610
18	91	201	50	311	—	2612	272	4077	—	2605	297	4010	—	440	153	—	—	1197	129	1881	—	7055	901	7956	10279	—	10279

[a]Four thinnings at mean d.b.h. 7.1, 9.1, 11.7, and 14.9.

Table 14.—Residual and cumulative thinned[a] volume per acre for 7-inch thinning and site index 70

Mean d.b.h. (inches)	Age	Residual basal area	White ash				Sugar maple				Yellow birch				Paper birch				Other				Combined					
			Thin		Residual		Thin		Residual		Thin		Residual		Thin		Residual		Thin		Residual		Thin		Residual			
			I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	All	I	II	All
	Years	*Ft²*	*Ft³/acre*																									
4	25	91	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	41	103	—	—	372	263	—	—	334	218	—	—	95	63	—	—	150	100	—	—	122	104	—	—	—	1073	748	1821
8	52	77	—	301	595	3	—	226	451	—	—	67	128	—	—	126	249	—	—	114	194	—	—	834	834	1617	3	1620
10	62	74	251	301	683	—	177	226	471	—	49	67	128	—	104	126	272	—	87	114	251	—	668	834	1502	1805	—	1805
12	72	94	251	301	976	—	177	226	659	—	49	67	171	—	104	126	383	—	87	114	448	—	668	834	1502	2637	—	2637
14	80	85	557	301	939	—	384	226	643	—	103	67	158	—	224	126	352	—	228	114	562	—	1496	834	2330	2654	—	2654
16	89	73	880	301	837	—	605	226	576	—	157	67	141	—	305	126	111	—	444	114	629	—	2391	834	3225	2294	—	2294
18	97	88	880	301	994	—	605	226	684	—	157	67	168	—	305	126	35	—	444	114	886	—	2391	834	3225	2767	—	2767
			Board feet/acre																									
4	25	91	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	-	—	—
6	41	103	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
8	52	77	—	381	1096	5	—	285	830	—	—	85	236	—	—	159	458	—	—	144	376	—	—	1054	1054	2996	5	3001
10	62	74	634	391	1961	—	448	285	1352	—	125	85	368	—	263	159	782	—	231	144	752	—	1701	1064	2765	5215	—	5215
12	72	94	634	391	3544	—	448	285	2392	—	125	85	620	—	263	159	1389	—	231	144	1692	—	1701	1064	2765	9637	—	9637
14	80	85	1746	391	3947	—	1199	285	2703	—	320	85	665	—	699	159	1480	—	762	144	2456	—	4726	1064	5790	11251	—	11251
16	89	73	3103	391	3519	—	2128	285	2420	—	549	85	593	—	1040	159	466	—	1707	144	2759	—	8527	1064	9591	9757	—	9757
18	97	88	3103	391	4179	—	2128	285	2874	—	549	85	704	—	1040	159	146	—	1707	144	3899	—	8527	1064	9591	11802	—	11802

[a] Four thinnings at mean d.b.h. 7.1, 9.3, 12.1, and 15.3.

Table 15.—Residual and cumulative thinned[a] volume per acre for 9-inch thinning and site index 50

Mean d.b.h. (inches)	Age	Residual basal area	White ash				Sugar maple				Yellow birch				Paper birch				Other				Combined					
			Thin		Residual		Thin		Residual		Thin		Residual		Thin		Residual		Thin		Residual		Thin			Residual		
			I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	All	I	II	All
	Years	*Ft²*	*Ft³/acre*																									
4	35	91	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	59	103	—	—	—	—	—	—	20	10	—	—	95	64	—	—	177	106	—	—	506	311	—	—	—	798	491	1289
8	83	107	—	—	—	—	—	—	24	12	—	—	116	77	—	—	201	121	—	—	664	391	—	—	—	1005	601	1606
10	106	79	—	—	—	—	2	16	40	—	9	102	190	—	2	24	—	—	49	518	1145	—	62	660	722	1375	—	1375
12	129	71	—	—	—	—	19	16	41	—	85	102	191	—	2	24	—	—	518	518	1190	—	624	660	1284	1422	—	1422
14	154	93	—	—	—	—	19	16	59	—	85	102	279	—	2	24	—	—	518	518	1731	—	624	660	1284	2069	—	2069
16	172	80	—	—	—	—	38	16	51	—	175	102	242	—	2	24	—	—	1078	518	1501	—	1293	660	1953	1794	—	1794
18	199	96	—	—	—	—	38	16	61	—	175	102	290	—	2	24	—	—	1078	518	1801	—	1293	660	1953	2152	—	2152
			Board feet/acre																									
4	35	91	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	59	103	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
8	83	107	—	—	—	—	—	—	45	22	—	—	213	141	—	—	370	272	—	—	1251	714	—	—	—	1879	1149	3028
10	106	79	—	—	—	—	4	38	115	—	21	244	544	—	5	56	—	—	119	1238	3345	—	149	1576	1725	4004	—	4004
12	129	71	—	—	—	—	58	38	146	—	278	244	691	—	5	56	—	—	1713	1238	4360	—	2054	1576	3630	5197	—	5197
14	154	93	—	—	—	—	58	38	247	—	278	244	1171	—	5	56	—	—	1713	1238	7371	—	2054	1576	3630	8789	—	8789
16	172	80	—	—	—	—	139	38	214	—	656	244	1016	—	5	56	—	—	4097	1238	6393	—	4897	1576	6473	7623	—	7623
18	199	96	—	—	—	—	139	38	257	—	656	244	1218	—	5	56	—	—	4097	1238	7667	—	4897	1576	6473	9142	—	9142

[a] Three thinnings at mean d.b.h. 9.0, 11.3, and 14.2.

Table 16.—Residual and cumulative thinned[a] volume per acre for 9-inch thinning and site index 60

Mean d.b.h. (inches)	Residual basal area	White ash				Sugar maple				Yellow birch				Paper birch				Other				Combined					
		Thin		Residual		Thin		Residual		Thin		Residual		Thin		Residual		Thin		Residual		Thin			Residual		
Age		I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	All	I	II	All
Years	*Ft²*	*Ft³/acre*																									
4	91	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	102	—	—	21	21	—	—	303	207	—	—	340	222	—	—	120	96	—	—	124	93	—	—	—	908	639	1547
8	107	—	—	27	27	—	—	350	238	—	—	401	261	—	—	193	154	—	—	156	117	—	—	—	1127	797	1924
10	77	—	29	39	—	3	261	531	—	3	287	585	—	2	173	238	—	2	130	241	—	10	880	890	1634	—	1634
12	97	—	29	64	—	3	261	872	—	3	287	960	—	2	173	39	—	2	130	396	—	10	880	890	2331	—	2331
14	89	18	29	67	—	249	261	902	—	273	287	994	—	37	173	—	—	113	130	411	—	690	880	1570	2374	—	2374
16	77	40	29	58	—	550	261	789	—	604	287	868	—	37	173	—	—	250	130	359	—	1481	880	2361	2074	—	2074
18	93	40	29	70	—	550	261	950	—	604	287	1046	—	37	173	—	—	250	130	432	—	1481	880	2361	2498	—	2498
		Board feet/acre																									
4	91	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	102	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
8	107	—	—	49	49	—	—	646	441	—	—	742	484	—	—	357	285	—	—	284	218	—	—	—	2078	1477	3555
10	77	1	69	113	—	7	631	1545	—	9	693	1700	—	4	418	689	—	3	312	699	—	24	2123	2147	4746	—	4746
12	97	1	69	234	—	7	631	3177	—	9	693	3498	—	4	418	145	—	3	312	1444	—	24	2123	2147	8498	—	8498
14	89	63	69	279	—	862	631	3795	—	950	693	4177	—	126	418	—	—	393	312	1726	—	2394	2123	4517	9977	—	9977
16	77	157	69	243	—	2126	631	3315	—	2342	693	3650	—	126	418	—	—	968	312	1509	—	5719	2123	7842	8717	—	8717
18	93	157	69	294	—	2126	631	3992	—	2342	693	4395	—	126	418	—	—	968	312	1817	—	5719	2123	7842	10498	—	10498

[a] Three thinnings at mean d.b.h. 9.1, 11.6, and 14.7.

Table 17.—Residual and cumulative thinned[a] volume per acre for 9-inch thinning and site index 70

Mean d.b.h. (inches)	Age	Residual basal area	White ash				Sugar maple				Yellow birch				Paper birch				Other				Combined					
			Thin		Residual		Thin		Residual		Thin		Residual		Thin		Residual		Thin		Residual		Thin			Residual		
			I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	All	I	II	All
	Years	*Ft²*	*Ft³/acre*																									
4	25	91	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	41	103	—	—	372	263	—	—	334	218	—	—	95	63	—	—	150	100	—	—	122	104	—	—	—	1073	748	1821
8	55	107	—	—	480	339	—	—	358	234	—	—	107	71	—	—	232	154	—	—	156	123	—	—	—	1333	921	2254
10	67	79	—	367	700	—	—	243	491	—	—	75	142	—	—	185	355	—	—	132	262	—	—	1002	1002	1950	—	1950
12	76	70	270	367	687	—	189	243	482	—	53	75	132	—	135	185	337	—	117	132	318	—	764	1002	1766	1956	—	1956
14	86	91	270	367	1007	—	189	243	718	—	53	75	192	—	135	185	324	—	117	132	598	—	764	1002	1766	2839	—	2839
16	94	77	604	367	898	—	427	243	641	—	117	75	171	—	217	185	62	—	322	132	640	—	1687	1002	2689	2412	—	2412
18	104	92	604	[illegible]	1073	—	427	243	765	—	117	75	204	—	217	185	—	—	322	132	852	—	1687	1002	2689	2894	—	2894
			Board feet/acre																									
4	25	91	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	41	103	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
8	55	107	—	—	904	638	—	—	674	440	—	—	201	134	—	—	436	291	—	—	309	231	—	—	—	2524	1734	4258
10	67	79	—	881	2047	—	—	584	1434	—	—	180	414	—	—	445	1038	—	—	316	797	—	—	2406	2406	5730	—	5730
12	76	70	926	881	2478	—	648	584	1742	—	182	180	477	—	465	445	1216	—	417	316	1190	—	2638	2406	5044	7103	—	7103
14	86	91	926	881	4233	—	648	584	3017	—	182	180	807	—	465	445	1362	—	417	316	2606	—	2638	2406	5044	12025	—	12025
16	94	77	2331	881	3774	—	1649	584	2693	—	450	180	720	—	811	445	261	—	1311	316	2800	—	6552	2406	8958	10248	—	10248
18	104	92	2331	881	4508	—	1649	584	3217	—	450	180	860	—	811	445	—	—	1311	316	3735	—	6552	2406	8958	12320	—	12320

[a] Three thinnings at mean d.b.h. 9.1, 11.5, and 14.7.

Table 18.—Residual and cumulative thinned[1] volume per acre (cubic-foot) for A-line thinning and site index 50

Mean d.b.h. (inches)	Residual basal area	White ash				Sugar maple				Yellow birch				Paper birch				Other				Combined					
		Thin		Residual		Thin		Residual		Thin		Residual		Thin		Residual		Thin		Residual		Thin			Residual		
Age		I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	All	I	II	All
Years	*Ft²*	*Ft³/acre*																									
4	35	91	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	57	92	—	—	—	—	—	—	23	11	—	10	106	59	—	14	184	92	—	202	581	102	—	226	226	894	264	1158
8	80	105	—	—	—	—	—	—	29	14	—	10	129	71	—	14	261	131	—	202	809	135	—	226	226	1228	351	1579
10	98	89	—	—	—	—	6	16	41	—	27	87	184	—	44	128	26	—	171	348	1306	—	248	579	827	1557	—	1557
12	133	106	—	—	—	—	6	16	56	—	27	87	253	—	44	128	—	—	171	348	1804	—	248	579	827	2113	—	2113
14	181	64	—	—	—	—	34	16	40	—	153	87	177	—	44	128	—	—	1070	348	1268	—	1301	579	1880	1485	—	1485
16	192	87	—	—	—	—	34	16	51	—	153	87	231	—	44	128	—	—	1070	348	1654	—	1301	579	1880	1936	—	1936
18	217	102	—	—	—	—	34	16	61	—	153	87	271	—	44	128	—	—	1070	348	1939	—	1301	579	1880	2271	—	2271
		Board feet/acre																									
4	35	91	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	57	92	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
8	80	105	—	—	—	—	—	—	54	26	—	—	242	134	—	—	489	244	—	—	1558	254	—	—	—	2343	658	3001
10	98	89	—	—	—	—	12	31	117	—	55	156	526	—	89	229	73	—	353	293	3829	—	509	709	1218	4545	—	4545
12	133	106	—	—	—	—	12	31	203	—	55	156	912	—	89	229	—	—	353	293	6647	—	509	709	1218	7762	—	7762
14	181	64	—	—	—	—	126	31	170	—	568	156	762	—	89	229	—	—	4080	293	5532	—	4863	709	5572	6464	—	6464
16	192	87	—	—	—	—	126	31	217	—	568	156	973	—	89	229	—	—	4080	293	7067	—	4863	709	5572	8257	—	8257
18	217	102	—	—	—	—	126	31	254	—	568	156	1140	—	89	229	—	—	4080	293	8280	—	4863	709	5572	9674	—	9674

[a] Three thinnings at mean d.b.h. 5.2, 8.3, and 14.0 inches.

Table 19.—Residual and cumulative thinned[a] volume per acre for A-line thinning and site index 60

Mean d.b.h. (inches)	Age	Residual basal area	White ash				Sugar maple				Yellow birch				Paper birch				Other				Combined					
			Thin		Residual		Thin		Residual		Thin		Residual		Thin		Residual		Thin		Residual		Thin			Residual		
			I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	All	I	II	All
	Years	*Ft²*	*Ft³/acre*																									
4	30	91	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	48	93	—	—	24	24	—	51	353	177	—	117	386	105	—	18	129	77	—	83	142	—	—	269	269	1034	383	1417
8	65	105	—	—	34	34	—	51	444	222	—	117	489	135	—	18	217	130	—	83	195	—	—	269	269	1379	521	1900
10	78	88	5	35	46	—	62	280	607	—	68	255	628	—	31	156	286	—	27	83	276	—	193	809	1002	1843	—	1843
12	94	103	5	35	69	—	62	280	915	—	68	255	947	—	31	156	115	—	27	83	417	—	193	809	1002	2463	—	2463
14	119	112	5	35	89	—	62	280	1165	—	68	255	1206	—	31	156	—	—	27	83	531	—	193	809	1002	2991	—	2991
16	141	76	45	35	60	—	575	280	794	—	599	255	822	—	31	156	—	—	261	83	362	—	1511	809	2320	2038	—	2038
18	158	92	45	35	73	—	575	280	961	—	599	255	995	—	31	156	—	—	261	83	439	—	1511	809	2320	2468	—	2468
			Board feet/acre																									
4	30	91	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	48	93	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
8	65	105	—	—	64	64	—	—	840	420	—	—	926	254	—	—	411	246	—	—	370	—	—	—	—	2611	984	3595
10	78	88	10	73	133	—	129	477	1744	—	141	289	1806	—	64	287	823	—	57	—	794	—	401	1126	1527	5300	—	5300
12	94	103	10	73	252	—	129	477	3310	—	141	289	3427	—	64	287	416	—	57	—	1511	—	401	1126	1527	8916	—	8916
14	119	112	10	73	373	—	129	477	4896	—	141	289	5070	—	64	287	—	—	57	—	2234	—	401	1126	1527	12573	—	12573
16	141	76	175	73	254	—	2285	477	3334	—	2375	289	3453	—	64	287	—	—	1042	—	1522	—	5941	1126	7067	8563	—	8563
18	158	92	175	73	308	—	2285	477	4039	—	2375	289	4182	—	64	287	—	—	1042	—	1844	—	5941	1126	7067	10373	—	10373

[a] Three thinnings at mean d.b.h. 5.2, 8.4, and 14.7 inches.

Table 20.—Residual and cumulative thinned[a] volume per acre for A-line thinning and site index 70

Mean d.b.h. (inches)	Age	Residual basal area	White ash				Sugar maple				Yellow birch				Paper birch				Other				Combined					
			Thin		Residual		Thin		Residual		Thin		Residual		Thin		Residual		Thin		Residual		Thin			Residual		
			I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	All	I	II	All
	Years	*Ft²*	*Ft³/acre*																									
4	25	91	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	40	93	—	55	422	223	—	87	383	146	—	59	106	—	—	19	159	79	—	94	139	—	—	314	314	1209	448	1657
8	53	105	—	55	591	313	—	87	443	169	—	59	127	—	—	19	251	126	—	94	193	—	—	314	314	1605	608	2213
10	63	89	79	378	815	—	58	259	562	—	17	59	154	—	34	152	339	—	26	94	301	—	214	942	1156	2171	—	2171
12	75	103	79	378	1051	—	58	259	718	—	17	59	194	—	34	152	454	—	26	94	468	—	214	942	1156	2885	—	2885
14	88	111	79	378	1348	—	58	259	920	—	17	59	249	—	34	152	325	—	26	94	617	—	214	942	1156	3459	—	3459
16	104	115	79	378	1542	—	58	259	1052	—	17	59	285	—	34	152	—	—	26	94	706	—	214	942	1156	3585	—	3585
18	114	80	747	378	1052	—	514	259	718	—	140	59	194	—	34	152	—	—	332	94	533	—	1767	942	2709	2497	—	2497
			Board feet/acre																									
4	25	91	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	40	93	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
8	53	105	—	—	1110	588	—	—	832	318	—	—	238	—	—	—	472	236	—	—	382	—	—	—	—	3034	1142	4176
10	63	89	161	660	2332	—	118	351	1609	—	34	—	442	—	70	272	969	—	56	—	899	—	439	1283	1722	6251	—	6251
12	75	103	161	660	3812	—	118	351	2602	—	34	—	703	—	70	272	1645	—	56	—	1766	—	439	1283	1722	10528	—	10528
14	88	111	161	660	5663	—	118	351	3866	—	34	—	1045	—	70	272	1365	—	56	—	2681	—	439	1283	1722	14620	—	14620
16	104	115	161	660	6481	—	118	351	4424	—	34	—	1196	—	70	272	—	—	56	—	3067	—	439	1283	1722	15168	—	15168
18	114	80	2969	660	4421	—	2035	351	3017	—	552	—	816	—	70	272	—	—	1385	—	2322	—	7011	1283	8294	10576	—	10576

[a] Three thinnings at mean d.b.h. 5.2, 8.4, and 16.3.

Table 21.—Example of model output at the end of poletimber-sawtimber-harvest phase for a typical northern hardwood stand

Quality-line thinning
Stand Number 1 started with: Site = 60
Number of trees/acre = 1,050
Basal area/acre = 91.00
Quadratic mean diameter = 4.0
Age of stand = 30; percent sawtimber = 15

Quality class	Species								
	BE	YB	SM	RM	PBA	WA	CON	OTHER	TOTAL
1	7.0%	23.0%	22.0%	1.0%	5.0%	1.0%	0.0%	0.0%	59.0%
FT2	6.4	20.9	20.0	0.9	4.5	0.9	0.0	0.0	53.7
2	4.0%	11.0%	11.0%	0.0%	3.0%	1.0%	0.0%	0.0%	30.0%
FT2	3.6	10.0	10.0	0.0	2.7	0.9	0.0	0.0	27.3
3	1.0%	4.0%	4.0%	0.0%	1.0%	0.0%	0.0%	1.0%	11.0%
FT2	0.9	3.6	3.6	0.0	0.9	0.0	0.0	0.9	10.0

ORDER OF SPECIES CLASS REMOVAL BY PRIORITY
24 20 17 23 18 19 21 22 16 12 9 15 10 11 13 14 8 4
1 7 5 2 3 6

ITHIN = 2, thin when stand reaches 30. FT2 above the B line
THINNING SPLOT NUMBER: 17
Q-LINE THINNING (THIN TO 80 FT2) WILL BE USED UP TO DIAMETER 6 INCHES
OPERATOR CONTROLS PAPER BIRCH REMOVAL PRIORITY
DIAMETER AT WHICH THINNING STARTED = 5.0
ROTATION AGE = 400
HARVEST DIAMETER = 18.0

THINNING NO. 1
Number of trees = 132.401 Quadratic mean diameter = 5.19 BA = 19.45

Quality class	Species								
	BE	YB	SM	RM	PBA	WA	CON	OTHER	TOTAL
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
FT2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FT3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	3.9%	4.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	8.4%
FT2	3.8	4.6	0.0	0.0	0.0	0.0	0.0	0.0	8.4
FT3	53.2	63.0	0.0	0.0	0.0	0.0	0.0	0.0	116.2
BF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	1.0%	3.9%	3.7%	0.0%	1.3%	0.0%	0.0%	1.2%	11.1%
FT2	1.0	3.9	3.7	0.0	1.3	0.0	0.0	1.2	11.1
FT3	13.3	53.7	51.2	0.0	18.2	0.0	0.0	16.4	152.9
BF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Mean diameter for age 49 = 6.096
Number of trees in stand = 460.79
Basal area of stand = 93.40
Percent sawtimber = 0

A-line number of trees present = 520.4 next yr = 504.7
B-line number of trees present = 303.4 next yr = 294.1
BA at A line = 101.37
BA at B line = 59.07

Table 21. (continued)

Harvest Yield in Percent

Quality class	Species								
	BE	YB	SM	RM	PBA	WA	CON	OTHER	TOTAL
1	15.2%	37.3%	41.0%	3.3%	0.0%	3.2%	0.0%	0.0%	100.0%
FT2	11.8	29.0	31.9	2.6	0.0	2.5	0.0	0.0	77.7
FT3 1	316.2	777.3	854.3	69.5	0.0	67.2	0.0	0.0	2084.4
BF	1328.8	3266.8	3590.5	292.0	0.0	282.6	0.0	0.0	8760.5
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
FT2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FT3 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
FT2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FT3 3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Total Yield from Thinnings

Quality class	Species								
	BE	YB	SM	RM	PBA	WA	CON	OTHER	TOTAL
FT2	16.2	43.2	45.0	3.6	10.2	3.5	0.0	0.0	121.7
FT3 1	371.2	973.8	1026.2	83.2	207.1	80.5	0.0	0.0	2742.0
BF	1250.3	3192.2	3425.5	279.2	545.5	270.0	0.0	0.0	8962.6
FT2	3.8	11.5	11.6	0.0	5.1	1.6	0.0	0.0	33.7
FT3 2	53.2	168.9	176.4	0.0	77.1	23.7	0.0	0.0	499.2
BF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FT2	1.0	3.9	3.7	0.0	1.3	0.0	0.0	1.2	11.1
FT3 3	13.3	53.7	51.2	0.0	18.2	0.0	0.0	16.4	152.9
BF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Total Yield

Quality class	Species								
	BE	YB	SM	RM	PBA	WA	CON	OTHER	TOTAL
FT2	28.0	72.1	76.9	6.2	10.2	6.0	0.0	0.0	199.5
FT3 1	687.4	1751.1	1880.5	152.7	207.1	147.7	0.0	0.0	4826.4
BF	2579.1	6458.9	7016.0	571.1	545.5	552.6	0.0	0.0	17723.1
FT2	3.8	11.5	11.6	0.0	5.1	1.6	0.0	0.0	33.7
FT3 2	53.2	168.9	176.4	0.0	77.1	23.7	0.0	0.0	499.2
BF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FT2	1.0	3.9	3.7	0.0	1.3	0.0	0.0	1.2	11.1
FT3 3	13.3	53.7	51.2	0.0	18.2	0.0	0.0	16.4	152.9
BF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

The total harvest per acre (including thinnings) is:
Basal area: 244.164 Cubic feet: 5,478.480 Board feet: 17,723.145

Solomon, Dale S.; Leak, William B. **Simulated yields for managed northern hardwood stands.** Res. Pap. NE-578. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1986. 24 p.

Board-foot and cubic-foot yields developed with the forest growth model SIMTIM are presented for northern hardwood stands grown with and without management. SIMTIM has been modified to include more accurate growth rates by species, a new stocking chart, and yields that reflect species values and quality classes. Treatments range from no thinning to intensive quality product management over a range of sites.

ODC: 524.37:62

Keywords: yields; northern hardwoods; growth; model

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**Northeastern Forest
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Clearcutting Affects Stream Chemistry in the White Mountains of New Hampshire

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Abstract

Clearcutting of northern hardwood forests in New Hampshire resulted in accelerated loss of dissolved nutrients to streams similar to that shown in experimental studies at Hubbard Brook. Stream water samples were collected during 4 years from nine watersheds that had been completely clearcut and from five nearby reference watersheds that were uncut. Differences in stream chemistry between clearcut and reference watersheds were greatest during the second year after cutting. During the 4 years of the study, specific conductance of the reference streams ranged from 20 to 30 μS/cm; average pH ranged from 5.0 to 5.7; nitrate ranged from less than 0.1 to about 4.0 mg/l; calcium from 1.0 to 3.0 mg/l; ammonium from less than 0.01 to 0.05 mg/l; magnesium from 0.2 to 0.8 mg/l; sodium from 0.6 to 1.6 mg/l; potassium from 0.1 to 0.7 mg/l; sulfate from 3.0 to 8.0 mg/l; and chloride from 0.3 to 0.6 mg/l. During the second year after clearcutting, specific conductance of streams draining the cuts ranged from 22 to 68 uS/cm; average pH ranged from 5.1 to 6.0; nitrate ranged from 1.4 to 27.3 mg/l; calcium from 1.4 to 6.7 mg/l; ammonium from less than 0.01 to 0.05 mg/l; magnesium from 0.3 to 1.4 mg/l; sodium from 0.8 to 3.0 mg/l; potassium from 0.1 to 1.5 mg/l; sulfate from 2.1 to 6.3 mg/l; and chloride from 0.4 to 0.9 mg/l. During the first year after cutting, streams from the cuts were more acidic than those from the reference streams; however, they were less acidic by the end of the second year. Concentrations of most ions in streams from clearcuts approached reference levels by the end of the fourth year after clearcutting, though streams from clearcuts remained less acidic by nearly a whole pH unit, sulfate remained depressed, and potassium remained elevated. During the 4 years following cutting, stream exports from cut sites exceeded those from reference sites by 57 kg/ha for inorganic nitrogen, 61 kg/ha for calcium, and 15 kg/ha for potassium.

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Introduction

Even-age forest management is practiced widely with many forest types in the Northeastern United States (USDA 1973). However, site changes created by clearcutting at the end of the management cycle may cause major changes in soil fertility and in water quality of streams flowing through the cut areas. Our paper examines these changes as they occur in northern hardwood forests on glaciated soils of the White Mountains of New Hampshire.

Soils underlying these forests are spodosols formed on glacial till and outwash. Under forest cover, these soils are characterized by organic horizons over mineral soil. Most of the available nutrients and, in turn, the majority of plant roots are found in the surface organic horizons (Hoyle 1973; Wood 1980). Because of low clay content, low basic minerals, and high acidity, the mineral horizons tend to be relatively infertile. Removal of the forest canopy during harvesting increases temperature and moisture in the forest floor, increases nitrification, and decreases uptake of water and nutrients by plants (Bormann and Likens 1979). The warmer, wetter microclimate leads to an increased rate of organic matter decomposition, nitrification, and mineralization, with a net reduction in the amount of humus (Hart 1961; Dominski 1971; Covington 1981). These processes rapidly convert unavailable nutrients in organic matter into available plant nutrients.

Abundant available nutrients, water, and light usually lead to rapid revegetation of the site by flora adapted to these disturbed conditions (Bormann and Likens 1979). However, because of the accelerated mineralization coincident with reduced net uptake and storage of nutrients by forest vegetation for the first few years after cutting, some of these available nutrients are leached to groundwater or streams (Bormann and Likens 1979). Different soils and vegetation types vary in their ability to retain these mineralized nutrients on the sites (Corbett et al, 1978; Vitousek and Melillo 1979).

In this paper, we present 4 years of postcutting data on stream water chemistry from nine clearcut watersheds dispersed throughout the White Mountains of New Hamphire. We compare stream water ion concentrations and nutrient removal between clearcut areas and adjacent uncut reference watersheds. Preliminary data from this study were published by Pierce et al. (1972), and nitrate and calcium data from these watersheds were published by Martin and Pierce (1980).

The objective of this study was to test the applicability of the findings of experimental clearcutting studies at the Hubbard Brook Experimental Forest in central New Hampshire (Pierce et al. 1970; Hornbeck et al. 1975; Likens et al. 1977) to a broader geographic area, and to document nutrient-cycling parameters that should be considered in evaluating the impact of clearcutting on site productivity.

The Study

Beginning in 1970, we examined numerous commercial clearcutting operations in the White Mountain National Forest to locate potential study sites. We located five areas with similar topography, vegetation, soils, and geology. Each area included at least one clearcut watershed and in two cases several clearcuts (Table 1). These sites had well-defined watersheds with perennial headwater streams, and all stems more than 5 cm in diameter at breast height (d.b.h.) had been cut. Each area had an adjacent or nearby uncut watershed that served as a reference (Reinhart 1967). Descriptions of the sites, volumes of trees before cutting, time of cutting, volume and species of wood removed, and maps were provided by the staff of the White Mountain National Forest.

Before cutting, all of the watersheds had been covered by second-growth forests, 50 to 100 years old. They contained the following ranges of species by volume: 1 to 40 percent sugar maple (*Acer saccharum* Marsh.); 8 to 17 percent yellow birch (*Betula alleghaniensis* Britton); 15 to 77 percent beech (*Fagus grandifolia* Ehrh.) and other northern hardwoods; and 3 to 30 percent spruce (*Picea rubens* Sarg.) and balsam fir (*Abies balsamea* (L.) Mill.).

Methods

Stream water samples were collected twice each month from April through November—and monthly during the winter—except at Hubbard Brook and East Branch, where samples were collected weekly. Specific conductance was measured in the field. Laboratory measurements included pH, concentrations of nitrate, calcium, magnesium, sodium, and potassium. Concentrations of ammonium, sulfate, and chloride were measured but not in all streams. The methods used for collecting samples, intensity of sampling, and procedures for chemical analyses were reported by Likens et al. (1977). Mean pH was calculated by converting pH to hydrogen ion concentrations, averaging, and reconverting to pH.

Watersheds were clearcut between 1968 and 1972 (Table 1), whereas stream water sampling began in the autumn of 1970 and continued through 1974. All of the clearcut watersheds were harvested between August and December before what we term the "first year after cut" (Figs. 1-6). Since the principal objective was to estimate stream water chemistry at different times after clearcutting, it was necessary to average stream water chemistry as follows: stream water concentrations in samples taken in 1971 for all stands cut in 1970 were averaged to represent the first year after cutting; stream water concentrations taken in 1971 for stands cut in 1969 were averaged to represent 2-year-old cuts along with concentrations collected in 1972 for stands cut in 1970, and so forth. Concentrations for the reference watersheds for 1971-74 also were averaged by years.

Table 1.—Site characteristics of the watersheds

Watershed	Total area	Aspect	Slope	Soil texture[a]	Northern Hardwoods	Bedrock Geology[b]	Year of Cut[c]
	ha		*Percent*		*Percent*		
				REFERENCE			
1. Gale River	49	NW	10	sl	90	kqm	—
2. Beaver Brook	50	W	15	sl	90	kqm	—
3. Conner Brook	45	NE	32	ls	80	lfg	—
4. East Branch	8	S	15	sl	70	bg	—
5. Hubbard Brook	13	S	20	sl	95	lfg	—
				COMPLETELY CLEARCUT			
6. Hubbard Brook	10	S	35	sl	95	lfg	1970A
7. East Branch	4	S	10	sl	70	bg	1970G
8. Gale River	2	NW	10	sl	95	kqm	1970G
9. Gale River	4	NW	10	sl	95	kqm	1969A
10. Gale River	24	N	10	sl	95	kqm	1971G
11. Gale River	14	N	10	sl	95	kqm	1972G
12. Beaver Brook	20	W	15	sl	90	kqm	1971A
13. Beaver Brook	14	W	15	sl	90	kqm	1971A
14. Conner Brook	8	NE	32	sl	80	lfg	1968A

[a] sl = sandy loam, ls = loamy sand. Conner Brook soils are in the Berkshire-Lyman-Marlow association; all other sites are in the Becket-Lyman-Hermon association.
[b] kqm = Kinsman quartz monzonite, bg = Bethlehem gneiss, lfg = Littleton formation sillimanite-zone gneiss with mica shist intrusions.
[c] A = autumn, October through mid-December; G = growing season, August and September.

Construction of the nutrient budgets required some assumptions. Previous work (Martin 1979) indicated that although the quantity of precipitation is quite variable throughout the White Mountains, precipitation chemistry is not. Consequently, precipitation chemistry was measured only at the Hubbard Brook Experimental Forest. Precipitation quantity was drawn from the National Weather Service volunteer network (NOAA 1971, 1972, 1973) and from Hubbard Brook. Volume-weighted ionic concentrations in precipitation from Hubbard Brook were summed by month. Monthly concentrations (mg/l) were multiplied by the estimated monthly precipitation quantity (l/ha) for each site. Then the total estimated monthly quantity for each ion from each site was summed for the year to give the input data as kg/ha/yr for each watershed. Streamflow estimates were derived for each area from a hydrologic model developed at the Hubbard Brook Experimental Forest (Federer and Lash 1978). This model estimates streamflow increases due to cutting and decreases due to revegetation. Output budgets were calculated by averaging monthly ionic concentrations in stream water and multiplying by the estimated monthly streamflow for each site and summed for the year.

Results

Although the results presented here are averages, the highest concentrations (as represented by the range bars in Figures 1-5) generally are from one particular watershed and the lowest are consistently from another. The differences in the results between cut watersheds probably reflect local differences in climate, weather, topography, soils, and glacial till. We have attempted to minimize these differences by averaging the data. In so doing we can discuss the general effects of harvesting on water chemistry in the region. But it must be realized that at any one site, the effects may be larger or smaller.

Specific Conductance

Specific conductance of the streams that drained the reference watersheds ranged between 20 to 30 μS/cm with few exceptions throughout the 4 years of the study (Fig. 1). No single stream was consistently higher or lower than the rest. A seasonal pattern was evident with the lowest values occurring in the summer and the highest values in the winter.

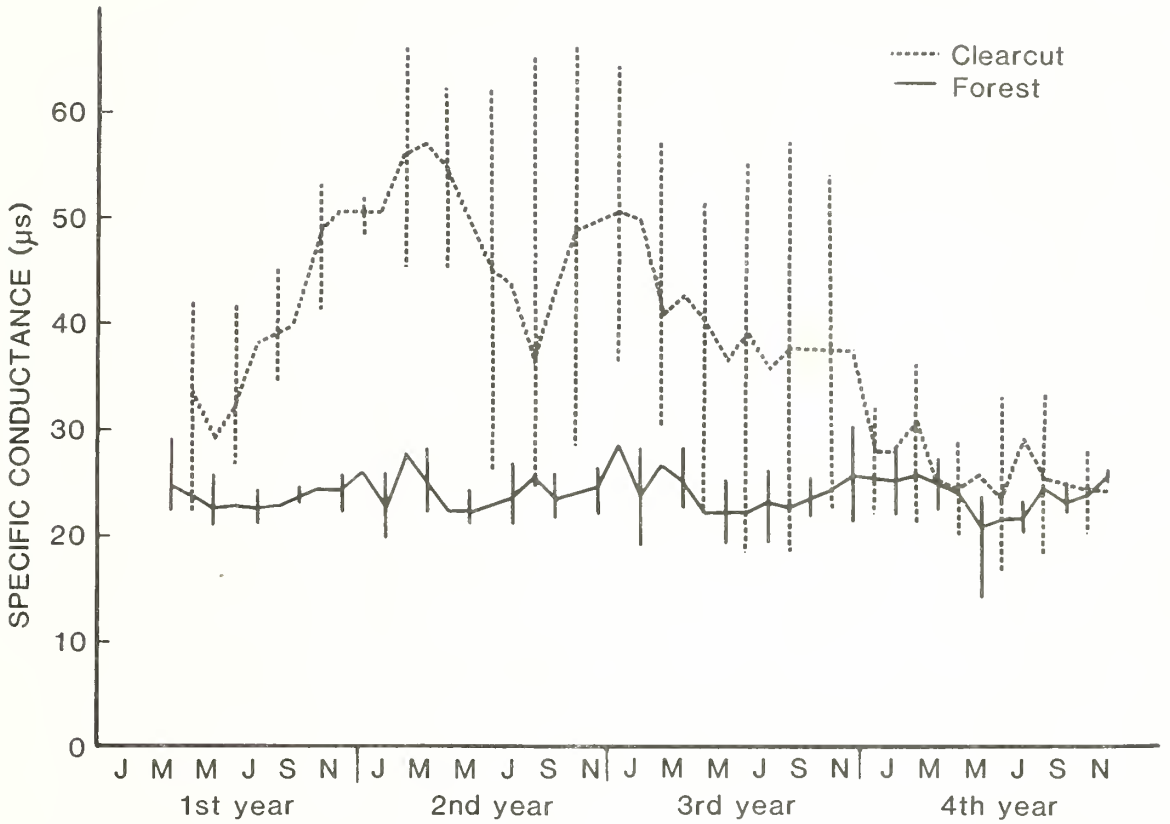

Figure 1.—Mean monthly specific conductance of streams from both forested and clearcut watersheds for 4 years after cutting (vertical bars represent the range of mean monthly data among the individual streams studied).

The first winter after cutting, specific conductance of the streams that drained clearcut watersheds was similar to that of the reference streams. But early in the first spring after cutting, the conductance began to rise. It increased steadily through the summer, autumn, and winter to peak during the spring of the second year after cutting (about 18 months after cutting). Although there was variation among watersheds, specific conductance of all streams rose steadily during this period. The maximum values for each stream during the first 18 months after cutting ranged from 48 to 66 μS/cm.

In most cases, conductance declined the second summer after cutting, only to increase again the next autumn (about 26 months after cutting). Specific conductance of the stream draining the clearcut at Hubbard Brook dropped to 24 μS/cm in September (21 months after cutting) and rose to only 35 μS/cm by December. At the other extreme, two streams at Gale River dropped only to about 59 μS/cm during the second summer after cutting, and rose to nearly 69 μS/cm during the autumn (25 months after cutting).

During the third year after cutting, specific conductance declined in all streams draining cut areas but the differences among these streams remained large, as indicated by the relative size of the range bars (Fig. 1). The streams at Hubbard Brook dropped below reference values while the two streams at Gale River remained above 47 μS/cm.

During the fourth year after cutting, the specific conductance of all of the streams draining clearcut watersheds returned nearly to reference levels. The variation among streams also was greatly reduced during the fourth year.

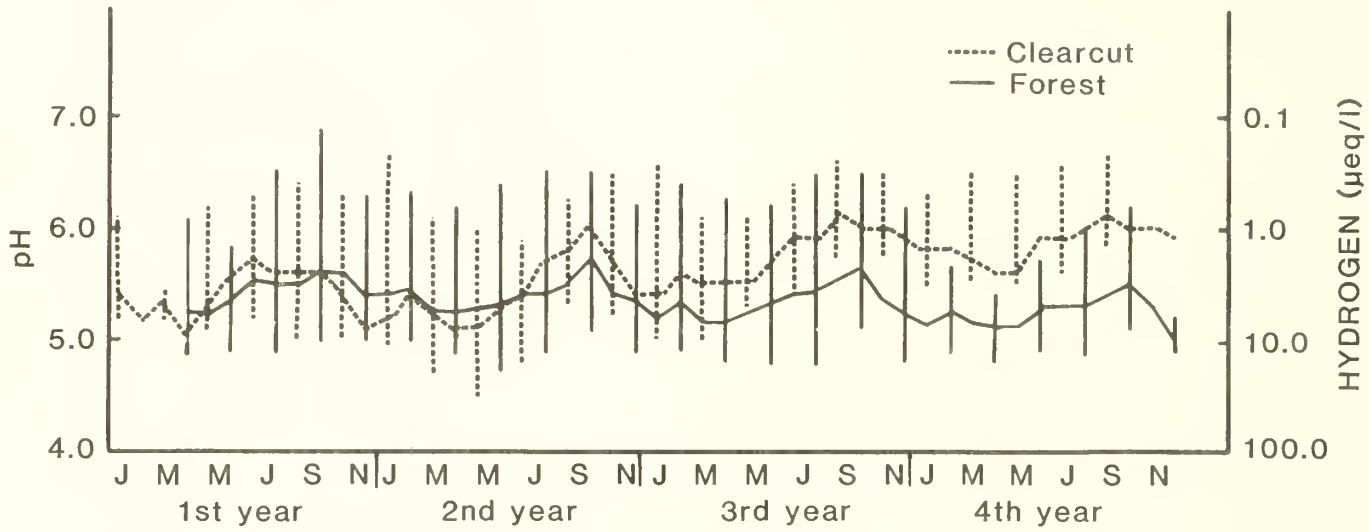

Figure 2.—Mean monthly pH of streams from both forested and clearcut watersheds for 4 years after cutting (vertical bars represent the range of mean monthly data among the individual streams studied).

pH

The range of pH was considerable both within and among the reference streams (Fig. 2). The average pH of all five reference streams ranged from 5.0 to 5.7. But the most acidic reference stream ranged from pH 4.7 to 5.1, while the least acidic dropped below pH 6.0 only six times in 30 months. Generally, conditions in the streams were most acidic during the snowmelt period in the spring, and least acidic during leaf fall in autumn.

During the first and second years after cutting, the mean and range of means of pH for all streams draining the clearcut watersheds were similar to those of the reference steams (Fig. 2). Although the average acidity for streams in reference and clearcut watersheds was similar, individual paired watersheds exhibited marked differences. For example, two streams from clearcut watersheds remained more acidic than their reference counterparts—with an average pH of about 5.5 versus 6.4 throughout the second year after cutting. But one stream from another clearcut remained less acidic than its reference, with an average pH of about 6.3 versus 5.5, throughout nearly all of the second year after cutting except in late summer and early autumn when their pH levels were similar.

In the third and fourth years after cutting, all streams draining clearcuts were less acidic than their paired reference watersheds; the average pH was about 6.0 versus 5.4 (Fig. 2).

Nitrate

Nitrate concentrations (Fig. 3) in the streams that drained the reference watersheds ranged from less than 0.1 mg/l to about 4.0 mg/l. A seasonal trend was apparent; concentrations were higher through the winter and spring than during the summer, a pattern similar to that reported in long-term studies of forested watersheds at Hubbard Brook (Likens et al. 1977). During the summer, nitrate concentrations dropped to less than 0.5 mg/l in some streams but remained higher than 2.0 mg/l in others.

All of the clearcut watersheds were harvested between August and December. The first year after cutting, nitrate concentrations in most of the streams draining these watersheds were higher than in the reference streams by February (2 to 6 months after cutting). Although there was wide variation among streams, nitrate concentrations in all cases continued to increase throughout the first year after cutting. Nitrate concentrations in all streams were highest between January and April of the second year (16 to 20 months) after cutting. This maximum value ranged between 23 to 28 mg/l among streams. Following the peak, nitrate in most of the streams began a steady decline that approached reference levels by the middle of the fourth year (48 to 54 months) after cutting. This decline was much more rapid in some cases than in others, as the range lines in Figure 3 indicate.

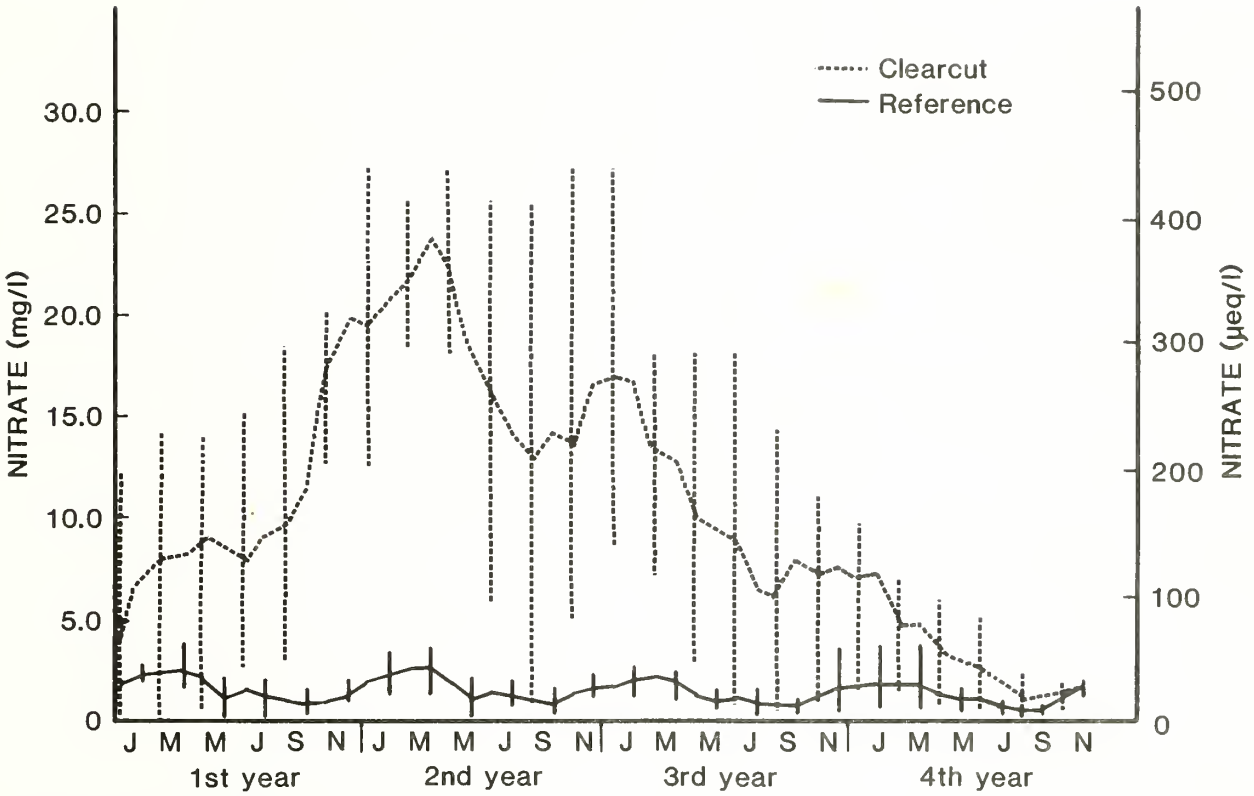

Figure 3.—Mean monthly nitrate concentrations in streams from both forested and clearcut watersheds for 4 years after cutting (vertical bars represent the range of mean monthly data among the individual streams studied).

Ammonium

Ammonium concentrations were measured in stream water from three pairs of reference and clearcut watersheds. Ammonium ranged from less than 0.01 to 0.05 mg/l, inclusive. No seasonal trends, treatment effects, or differences between watersheds were apparent.

Calcium

Calcium concentrations in the reference streams ranged from 1.0 to 3.0 mg/l (Fig. 4). Variation among streams or over time within individual streams was slight.

Calcium concentrations in the streams draining harvested watersheds began to rise immediately after clearcutting. Values generally were highest (6.5 to 8.1 mg/l) during the winter of the second year (12 to 16 months) after cutting. Calcium in the stream at Hubbard Brook (lower limit of range lines in Figure 4) had returned to reference levels 28 months after cutting; but in two streams at Gale River (upper limits of the range bars in Figure 4), calcium concentrations were twice those of reference levels 50 months after cutting.

Magnesium

Magnesium concentrations in the reference streams were stable, varying by no more than 0.1 mg/l over the 4 years of the study. There was some variation between watersheds: one averaged 0.2 mg/l; another averaged 0.8 mg/l.

Following clearcutting, magnesium concentrations generally rose slowly throughout the first year (Fig. 5) and peaked in the second year after cutting. In some streams, this peak occurred early in the spring of the second year, in some in midsummer, and in others not until late autumn (2 full years after cutting). Generally, this second-year peak, as high as 1.4 mg/l, was 3 to 5 times as large as the concentrations in the paired reference streams.

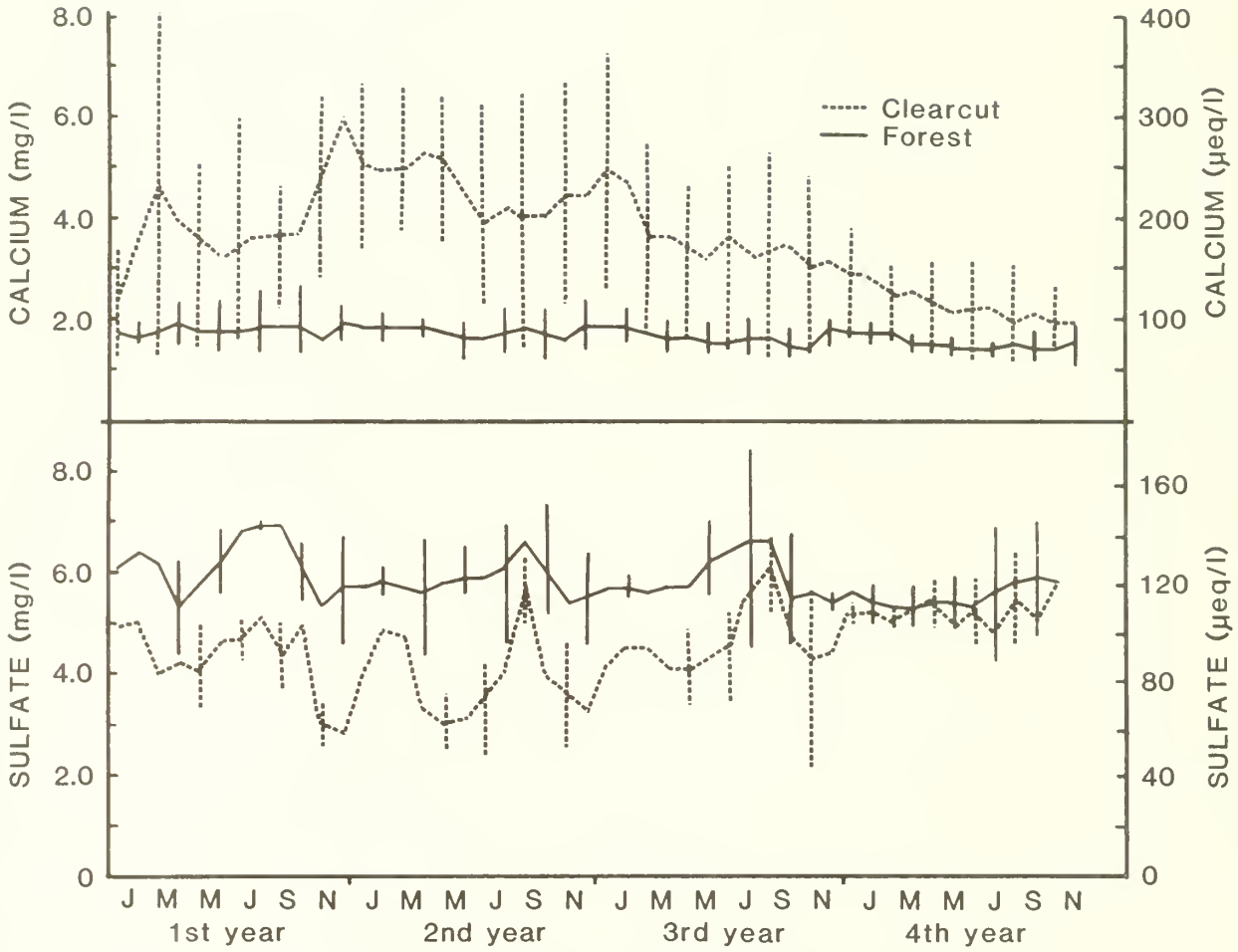

Figure 4.—Mean monthly calcium and sulfate concentrations in streams from both forested and clearcut watersheds for 4 years after cutting (vertical bars represent the range of mean monthly data among the individual streams studied).

Magnesium concentrations declined slowly throughout the third and fourth years after cutting. Examination of individual grouped watersheds revealed that magnesium concentrations in about half of the streams returned to reference levels by the summer of the fourth year, while the remainder at 0.6 mg/l were at least double reference levels after 50 months.

Sodium

Sodium concentrations in the reference streams ranged from 0.6 to 1.6 mg/l. A seasonal pattern was apparent: the higher concentrations usually were recorded in late summer and the lower concentrations in the spring. This pattern likely resulted from a dilution effect during spring snowmelt (Johnson et al. 1969). Following cutting, sodium concentrations rose steadily through the first 2 years to 3.0 mg/l in some cases (Fig. 5). In the spring of the fourth year after cutting, sodium, in all streams, decreased below reference levels for several months and then returned to reference levels.

Potassium

Potassium levels in the streams draining reference watersheds ranged from 0.1 to 0.7 mg/l, with most streams near 0.3. Following clearcutting, mean monthly concentrations ranged from 0.1 to 1.5 mg/l, with the average at 0.7 mg/l. However, on a paired-watershed basis, potassium concentrations were 3 to 4 times greater than reference levels following cutting, and they remained elevated throughout the study. There was neither an obvious second-year peak nor a gradual return toward reference levels during the 4 years (Fig. 5).

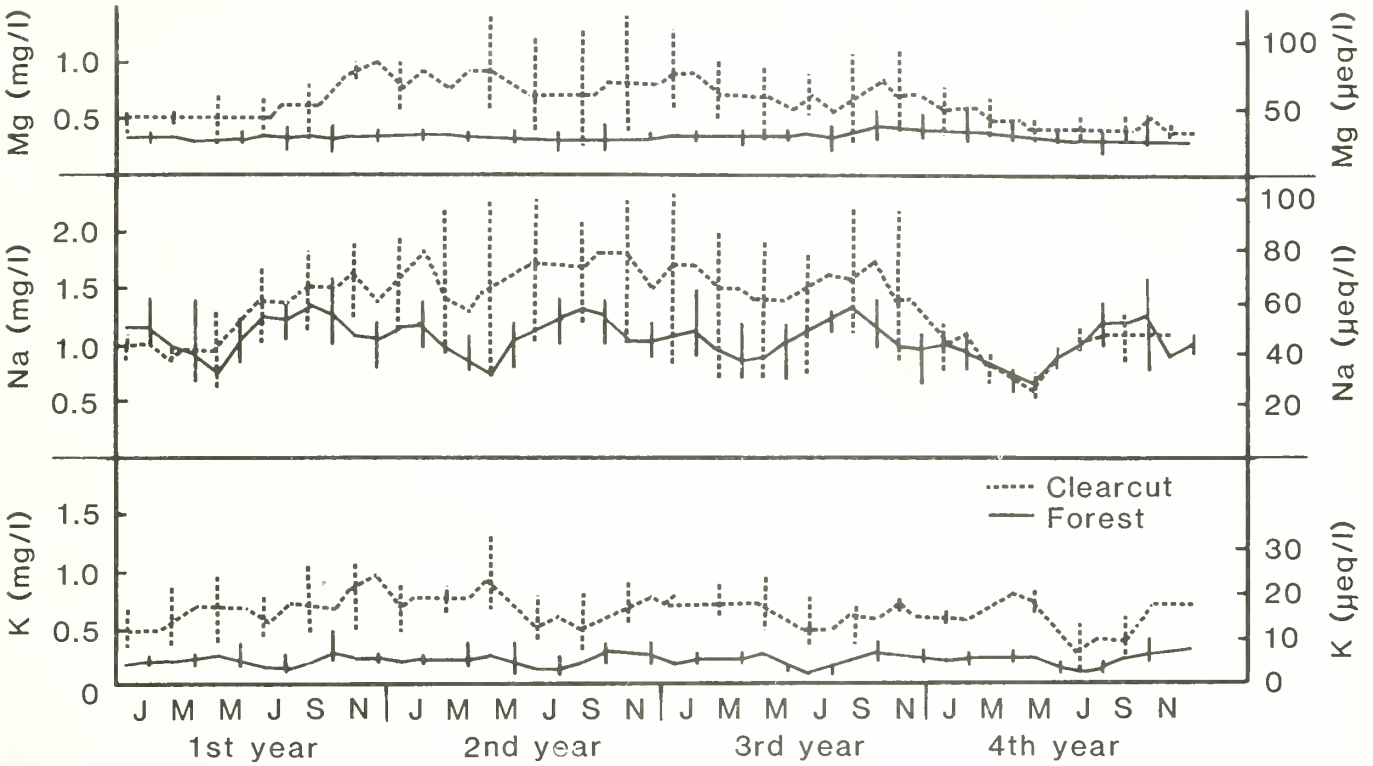

Figure 5.—Mean monthly magnesium, sodium, and potassium concentrations in several streams from both forested and clearcut watersheds for 4 years after cutting (vertical bars represent the range of mean monthly data among the individual streams studied).

Sulfate

Sulfate concentrations in the streams that drained both reference and clearcut watersheds were variable both among streams and from month to month in the same stream (Fig. 4). Sulfate in the streams that drained clearcut watersheds were below reference levels after cutting, and remained so throughout this study.

Chloride

During the first 2 years after cutting, average chloride concentrations from reference watersheds ranged from 0.3 to 0.6 mg/l. Those from the clearcuts ranged from 0.4 to 0.9 mg/l. During the third and fourth years after cutting, both reference and clearcut values ranged from 0.2 to 0.8 mg/l.

Downstream Concentrations

The stream system at Gale River provided us with an opportunity to compare dilution effects downstream from the clearcuts. A headwater stream was used as the forested reference. Samples were collected from several small streams that drained 100 ha that had been completely clearcut, and the data were averaged. Collections were also made downstream at points where the clearcutting represented 63, 17, 13, and 6 percent of the area of the watershed.

Only nitrate data are presented (Fig. 6) because that ion reacted most dramatically to clearcutting. These data indicate that the smaller the area of a watershed clearcut, the smaller the increase in concentration. Nitrate concentrations in streams from the watersheds with 13 and 6 percent of the area clearcut were not different from the reference values.

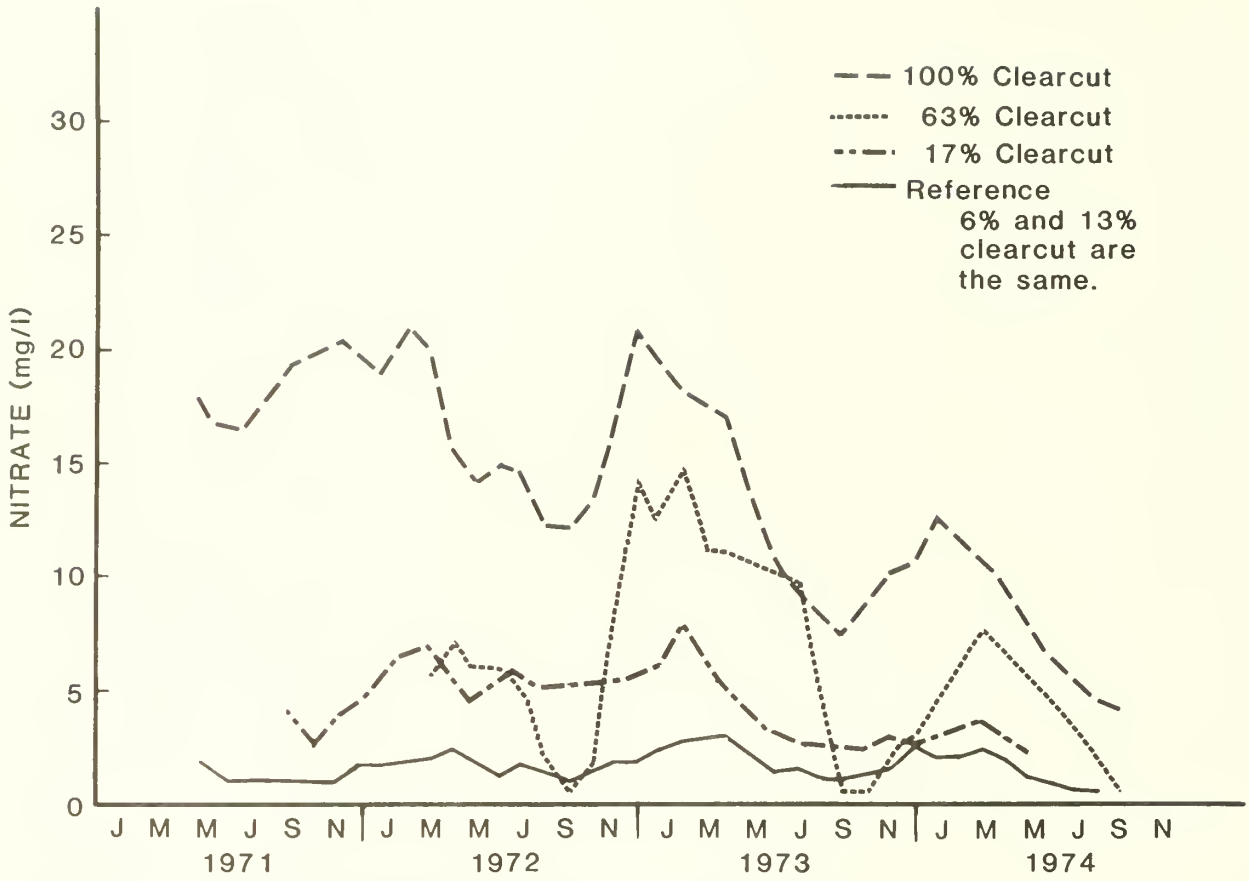

Figure 6.—Mean monthly nitrate concentrations in streams from an uncut, completely clearcut, and four partially clearcut watersheds. Data from the streams draining watersheds that were 13 and 6 percent clearcut were the same as from the reference.

Input-Output Nutrients Budgets

It is useful to know the total quantity of an element that has been removed from a watershed via streamflow. Nutrient flux values are presented to indicate the mass inflow and outflow of ions per hectare of watershed per year (Table 2). Losses of nutrients in particulate matter due to erosion were not considered, but are likely to have been small (Bormann et al. 1974).

Dissolved inorganic nitrogen (NO_3-N plus NH_4-N) in precipitation averaged 7.5 kg/ha/yr (Table 2) over the 2-year period. The reference watersheds lost 3.7 kg/ha/yr in streamwater for a net gain of 3.8 kg/ha/yr of inorganic nitrogen. This net gain compared favorably with the long-term mean of 2.5 kg/ha/yr observed for forested watersheds at Hubbard Brook from 1963 to 1974 (Likens et al. 1977).

Watersheds that had been clearcut for 1 year lost 2.2 times as much inorganic nitrogen as entered in precipitation. Losses the second year after cutting were 4 times greater than inputs. The net loss of inorganic nitrogen over the 4-year period was 42 kg/ha. For the same period, the reference watersheds were accumulating 15 kg/ha N (Table 2). On the basis of precipitation inputs and streamflow outputs only, by the fourth year after cutting, inorganic nitrogen was beginning to accumulate in the harvested watersheds again by about 2 kg/ha/yr. Gaseous exchange of nitrogen was not considered.

Small quantities of the cations (Ca^{++} and K^{+}) entered the watersheds dissolved in precipitation, and relatively large quantities were lost from the reference watersheds (Table 2). The second year after cutting, cation losses from cutover watersheds were nearly 3 times those from the reference watersheds. Over the 4-year span, 61 kg/ha of additional calcium and 15 kg/ha of additional potassium were removed from the harvested watersheds than from the references in stream water.

Table 2.—Input-output budgets. Input data are ionic additions from precipitation only; output data from the references and the clearcuts are dissolved substance losses to streamwater

Item	Nitrate nitrogen	Ammonium nitrogen	Calcium	Potassium
	kg/ha/yr			
Input (precipitation)	5.4 (1.4)[a]	2.1 (0.5)	1.2 (0.3)	0.6 (0.2)
Output (references)	3.6 (1.9)	0.1 (0.1)	12.5 (4.3)	2.0 (0.7)
Output (clearcuts)				
1st year after cutting	16.6 (3.7)	0.1 (0.1)	30.4 (10.1)	5.8 (1.9)
2nd year after cutting	29.7 (4.6)	0.1 (0.1)	32.9 (4.3)	5.7 (2.0)
3rd year after cutting	19.8 (8.4)	0.2 (0.1)	29.8 (9.2)	5.2 (1.9)
4th year after cutting	5.0 (3.3)	0.2 (0.1)	17.8 (3.0)	6.0 (2.0)

Item	Inorganic nitrogen[b]	Calcium	Potassium
	kg/ha		
	4-YEAR SUMMARY		
Inputs minus outputs (references)	+ 15.2	− 45.2	− 5.6
Input minus output (clearcuts)	− 41.7	− 106.1	− 20.3
Net change (references minus clearcuts)	− 56.9	− 60.9	− 14.7

[a] Standard error.
[b] Nitrate plus ammonium.

Discussion

Clearcutting northern hardwood ecosystems sets in motion complex hydrological, biogeochemical, and ecological changes. Removal of the forest canopy:
(1) increases soil temperature; (2) reduces transpiration;
(3) increases soil moisture and streamflow;
(4) increases decomposition of organic matter;
(5) increases mineralization and nitrification; and
(6) increases exchange of ions in the soil (Bormann and Likens 1979; Likens et al. 1970; Federer and Gee 1974; Federer 1973; Hornbeck et al. 1970; Covington 1981; Dominski 1971).

These changes, in turn, trigger a complex array of vegetative growth responses so that cutover sites are revegetated quickly. Increases in water, nutrients, and temperature resulting from cutting are reduced quickly as vegetation regrows; within a few years, these variables approach precutting levels. However, nutrient uptake by vegetative growth is, at first, less than nutrient release by accelerated mineralization; consequently, nutrients are lost from some systems in drainage water (Bormann et al. 1974; Bormann and Likens 1979).

This study and that of Pierce et al. (1972) confirm the findings of experimental studies at Hubbard Brook (Likens et al. 1970; Pierce et al. 1970) that commercial clearcutting of northern hardwoods throughout the White Mountain region results in accelerated nutrient loss in drainage water. The general pattern of nutrient loss in drainage water shows a maximum in the second year after cutting, with a general decline to near reference levels by the fourth year. This pattern is similar to that seen in the experimentally deforested watershed, W2, at Hubbard Brook.

Not all ions followed the same patterns. Nitrate, calcium, magnesium, sodium, and chloride peaked in the second year and then declined to reference levels by the fourth year. Potassium showed no obvious second-year peak nor a gradual return to reference levels. Sulfate concentrations dropped well below reference levels after cutting but returned to reference levels during the fourth year.

Although the average pH values showed no distinct patterns of change during the first 2 years after cutting, comparisons of stream water pH for individual

paired watersheds (cut versus reference) showed discernible differences—generally, acidity was greater immediately after cutting. This increase probably was due in part to increased nitrification, which caused the release of additional nitrate and hydrogen ions to the streams immediately after cutting (Bormann et al. 1968; Likens et al. 1969; Bormann and Likens 1979; Vitousek et al. 1979). While the implications of increased acidity to stream water biota are not fully understood, there is evidence that low pH mobilizes soil aluminum that can be leached to streams and that may be injurious to aquatic life (Johnson 1979; Hall et al. 1980; Driscoll and Likens 1982). Also, Eaton et al. (1973) and Hornbeck et al. (1977) have shown that the forest canopy plays a major role in neutralizing acidic precipitation during the summer in New Hampshire. Removal of the canopy by harvesting may contribute to the increased acidity of the streams during the first year after clearcutting (Fig. 2). Many forest streams in New Hampshire currently are marginal for trout production because of the low pH and high concentrations of aluminum. A further decrease in pH, even for short periods, may be detrimental.

There is no clear explanation for the gradual decrease in acidity for the clearcut watersheds during the third and fourth years.

Our data indicate that nitrate concentrations in streams draining watersheds clearcut during the growing season usually are higher than those in streams from watersheds cut during the dormant season (Table 3). However, both the watershed with the highest concentration of nitrate in the stream and the one with the least were cut in the dormant season.

Table 3.—Mean annual nitrate concentrations (± standard error) from three watersheds cut during the summer growing season and from three watersheds cut during the autumn dormant season

	Cut	
Year after cut	Growing season	Dormant season
	mg/l	
First	14.2 ± 4.0	11.3 ± 6.5
Second	20.4 ± 4.6	12.6 ± 6.9
Third	13.4 ± 5.2	6.3 ± 4.5

Nutrient concentrations in streams draining clearcuts decrease distinctly as the proportion of the watershed cut becomes smaller. Dilution occurs as water with low concentrations of nutrients enters the streams from uncut areas, either from tributary streams or from subsurface flow. Chemical reactions within the stream and nutrient assimilation by the organisms in the stream channel itself and in the bottom sediments may contribute to the reduction in nutrients with distance downstream (Sloane 1979). Whatever the reason, our data show that 10 to 15 percent of a watershed in the White Mountains could be clearcut without measurably affecting the nitrate and calcium levels in streamflow at the base of the watershed.

If it is desirable to clearcut larger proportons of a watershed, it would seem prudent to harvest in a series of small cuttings spaced at least 2 years apart. The 2-year spacing would minimize the synchronization of maximum nutrient loss the second year after cutting over large areas of a watershed (Hornbeck et al. 1975).

Our estimated losses of nutrients in streamwater from commercially cut northern hardwood forests are substantially less than from the experimentally devegetated watershed, W2, at Hubbard Brook (Table 2) (Likens et al. 1970; Pierce et al. 1972). Nevertheless, the amounts of nutrients lost are not insignificant. Over the 4 years after cutting, losses (net change for reference minus net change for cutover) of 57, 61, and 15 kg/ha for N, Ca^{++}, and K^{+} constitute about 70, 98, and 23 percent of the annual estimated uptake for these elements (Likens et al. 1977). Compared to the total amounts of these elements in the system, these losses are small, but it is not known how they compare to the actual proportion of the total that is available for use by the vegetation. Studies underway at Hubbard Brook suggest that losses of this magnitude will not reduce production substantially so long as sufficient time is allowed between cuts for the ecosystem to reaccumulate nutrients from the atmosphere, weathering, or biological fixation. At this time, the 100-year rotation in northern hardwood forests used by the USDA Forest Service seems ample. However, repeated short rotations might ultimately prove deleterious to future productivity.

Conclusions

1. Clearcutting of northern hardwood forests on glacial till throughout northern New Hampshire resulted in a response similar to that of experimentally clearcut watersheds at Hubbard Brook. Substantial quantities of nutrients were lost in drainage water during a 4-year period after cutting.

2. Conductivity of the streams draining clearcuts more than doubled during the second year after cutting but returned to reference levels during the fourth year.

3. Streams became slightly more acidic during the first year after clearcutting; however, during the third and fourth years after cutting, the streams were substantially less acidic than the references. Greater acidity may have adverse consequences for fish and invertebrates in streams that are marginal habitats with respect to pH levels before cutting.

4. Concentrations of nitrate nitrogen, calcium, magnesium, sodium, and potassium increased substantially in the streams from the clearcuts during the first 3 years after cutting, representing losses of these plant nutrients from the forest soils to streams.

5. Concentrations of sulfate decreased in streams draining the clearcuts during the first 3 years after cutting.

6. Clearcutting seemed to have almost no effect on the concentrations of chloride and ammonium nitrogen.

7. All ions except hydrogen and potassium returned to reference levels in the streams from the clearcuts. By the end of the fourth year after cutting, there were considerably fewer hydrogen ions and considerably more potassium ions in the streams from harvested areas than in those from the reference areas with no indicaton of impending recovery.

8. Concentrations of ions in streamwater were diluted in proportion to the area of the watershed clearcut. Clearcutting about 15 percent of a watershed did not measurably change the chemistry of the major streams in the watershed.

9. Clearcutting during the dormant season affected stream chemistry less than harvests during the growing season.

10. During the 4 years of study, the clearcut watersheds lost 57 kg/ha of inorganic nitrogen, 61 kg/ha of calcium, and 15 kg/ha of potassium in streamflow. This loss does not include losses in forest products removed, accelerated denitrification, or gains due to fixation, which were not measured.

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Commercial clearcutting of northern hardwood forests changed the chemistry of the streams that drained from them. By the second year after cutting, specific conductance doubled, nitrate increased tenfold, calcium tripled, and sodium, magnesium, and potassium doubled. Chloride and ammonium did not change; sulfate decreased. Concentrations of most ions returned to reference levels after 4 years, though sulfate remained depressed, potassium remained elevated, and acidity decreased.

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A Regional Analysis of Pallet Supply and Demand

William G. Luppold
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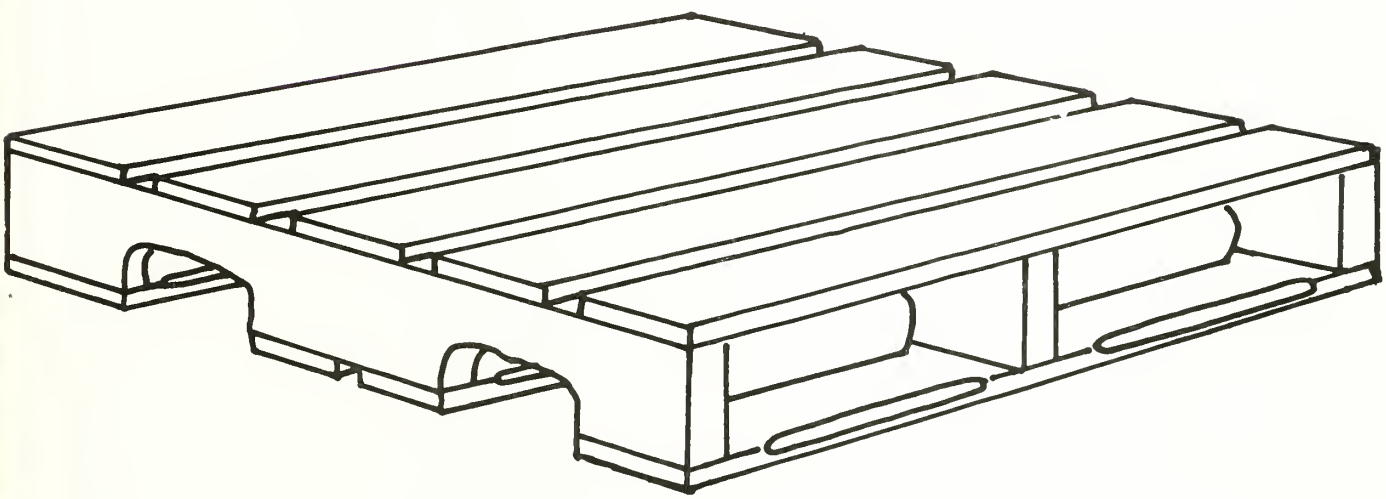

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Abstract

Eight regional demand and supply equations for pallets were developed in this study. Demand for pallets is affected by the price pallet users receive for their products, the price pallet users pay for labor, and past price of labor versus the cost of new capital equipment as approximated by interest rates. Pallet production is affected by pallet price, past lumber price, past wage rates in the pallet industry, and an index of labor productivity. Results indicate that forces outside of the pallet market tend to influence pallet demand, while forces inside of the pallet market greatly influence pallet supply. However, since the level of demand has a great deal of influence on pallet price, it is concluded that the pallet market is strongly influenced by overall general economic activity, while it is only weakly influenced by activity within the forest products markets.

Introduction

The pallet industry has grown rapidly since 1935, with major growth periods in the early and late 1970's (Fig. 1). Both of these strong growth periods were marked by increasing industrial output coupled with escalating labor costs. The only major downturn in pallet production occurred during the 1974-75 and 1981-82 economic recessions.

In 1982, the pallet industry consumed more than 3 billion board feet of hardwood lumber and more than 600 million board feet of softwood lumber. These quantities represent a minimum of 36 percent of the hardwood lumber and 9 percent of all lumber consumed in the United States during 1982. This level of consumption makes the pallet industry the largest user of hardwood lumber and the second largest user of all lumber in the United States.

If present pallet use and pallet construction methods are continued, the resulting demand for hardwood lumber for pallets has the potential to cause regional problems in the supply of hardwood raw material. In order to assess the impact that the pallet industry will have on the regional distribution of our hardwood resource in the future, information on the regional demand, supply, and price of pallets is needed.

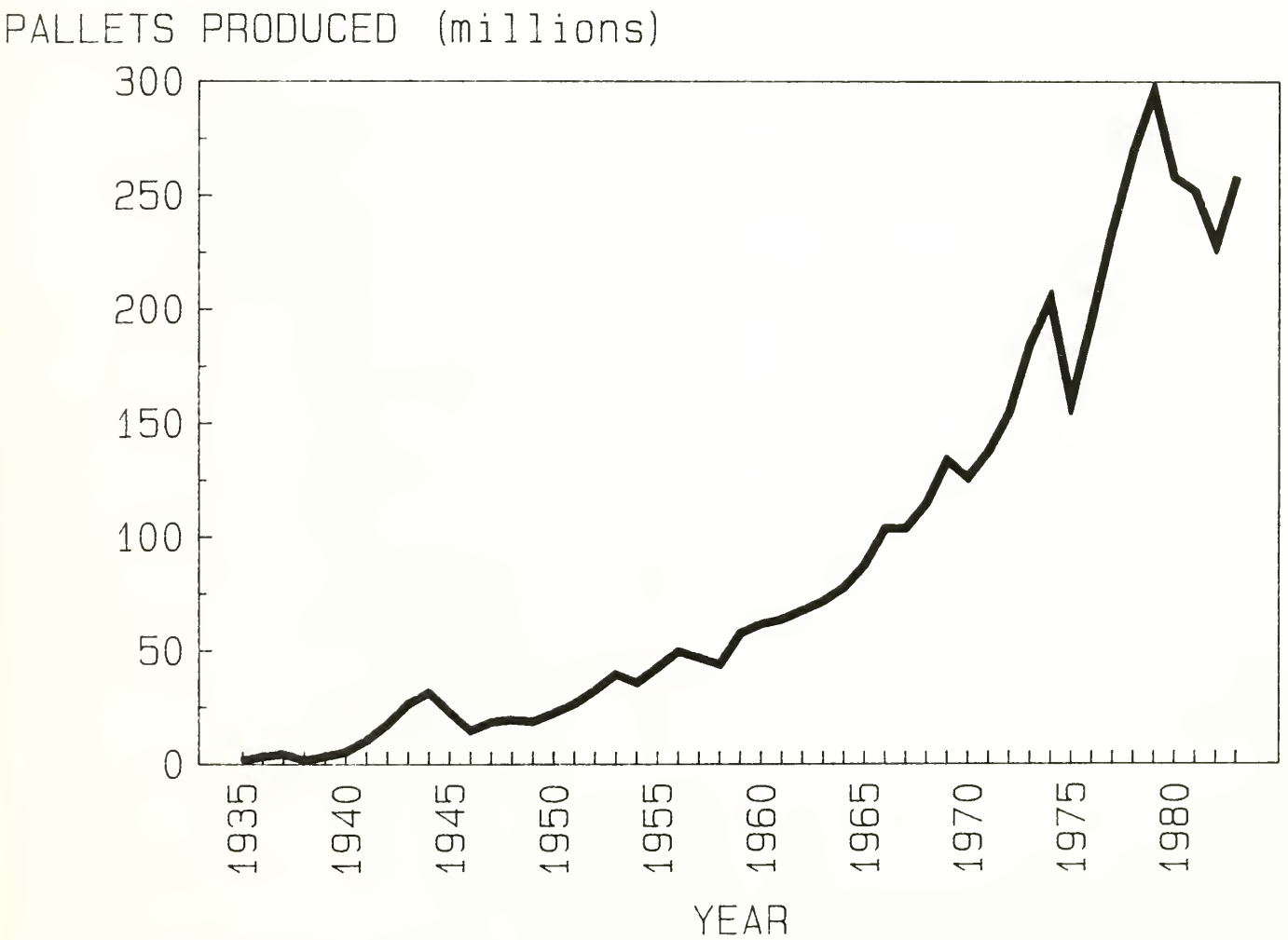

Figure 1.—Pallet production 1935-83.

The Pallet Market

Pallets are produced nationwide at approximately 1,800 plants employing more than 23,000 workers (U.S. Department of Labor 1984[1]). Pallets are an inexpensive product produced from low-grade lumber at relatively small plants that employ unskilled or semi-skilled labor. However, the cost of transporting pallets is high relative to the cost of pallet production. Therefore, pallets are normally produced in close proximity to the purchaser.

Pallet firms tend to produce for local or regional markets, depending in part on the size of the firm. Very small firms tend to compete solely in local markets, while the larger firms tend to compete in larger geographic areas. In a study of pallet firms in the Northeast by Bond and Sendak (1970), nearly 50 percent of the firms employed fewer than 10 persons and competed entirely in local markets.

Factors Affecting the Supply and Demand of Pallets

The major factors that affect pallet demand and supply—along with the variables that represent these factors, the influence of these factors on demand or supply, and the time it takes for a change in these factors to affect the pallet market—are listed in Tables 1 and 2, respectively.

Because pallets are low-value products with relatively high transportation costs, it is assumed that regional pallet demand equals regional pallet supply. This assumption implies a separate set of demand and supply equations for each region. Therefore, quarterly equations were estimated for each of eight census regions of the United States. These regions as defined by the U.S. Department of Commerce are:

Region	*State*
New England	ME, NH, VT, MA, RI, CT
Middle Atlantic	NJ, NY, PA
East North-Central	OH, IL, IN, MI, WI
West North-Central	MN, IA, MO, ND, SD, NB, KS
South Atlantic	DE, MD, VA, WV, NC, SC, GA, FL
East South-Central	AL, KY, TN, MS
West South-Central	AR, LA, OK, TX
Pacific	CA, OR, WA

[1]U.S. Department of Labor, Bureau of Labor Statistics. ES-202 program, employment and wages, SIC 2448, quarterly data for period 1975 through 1983. Unpublished report. Washington, DC: U.S. Department of Labor, Bureau of Labor Statistics; 1984. 58 p.

The factors affecting the demand and supply of pallets are derived from economic theory and observation of the pallet market. Using economic theory, we ascertain that pallet demand is positively affected by the price pallet users receive for their product (output price) and negatively affected by the price of pallets and the price of labor. The ratio of wage rates to capital is included in the demand equation to account for the trade-off between a labor-intense system employing manpower and a capital-intense system employing pallets.

Economic theory also indicates that the supply of pallets is positively affected by the price of pallets and negatively affected by the price pallet producers pay for labor and lumber. Pallet supply is also affected by changes in production processes leading to greater labor productivity. To account for this change, a labor productivity index has been included in the supply equations.

A mathematical representation of the demand and supply equations, along with a full description of the variables in these equations, is presented in Appendix A. The weight scheme used to develop the regional output price and demanders' wage rates is in Appendix B. The species used to calculate regional lumber price are in Appendix C.

The impact time periods associated with the different variables in the demand and supply equations represent the time it takes pallet users or producers to react to changes in the variables listed in Tables 1 and 2. The choice of the length of the impact times was based on observation of the pallet production and purchasing decisions and empirical evidence gained through statistical estimation of the demand and supply equations. These impact times may or may not be representative of the behavior of any particular pallet producer or user, but are representative of the aggregate or total demand and supply forces at work in the pallet market.

The impact period of 4 to 6 quarters associated with pallet price in the demand equation (Table 1) indicates that after a change in pallet price, it takes pallet users about a year to start to react and another 4 quarters to fully react to this change. The length of time it takes pallet users to react to changes in pallet prices is affected by the way in which pallets are purchased. Because pallets are a minor input in the manufacturing and distribution costs for pallet-using industries, the decision to purchase pallets is made on an annual or semi-annual basis and is, therefore, probably based on expected future pallet price. The expected price is, in turn, probably based on past pallet prices. The reaction time between changes in pallet price and pallet demand is further retarded by the 1- to 6-month time period between the decision to purchase pallets and the actual ordering of pallets.

Table 1.—Major factors affecting pallet demand, the impact of these factors on pallet demand and the length of time it takes these factors to impact demand. The names of variables used to represent the factors are in parentheses

Factor	Impact of factor	Impact time
Regional price index of products produced by industries that use pallets (output price)	Positive	Immediate
Price of pallets (pallet price)	Negative	4 to 6 quarters
Regional wage rates in industries that use pallets (demanders' wage rate)	Negative	Immediate
Ratio of wage rates to interest rates (wage interest ratio)	Positive	9 to 12 quarters

Table 2.—Major factors affecting pallet supply, the impact of these factors on pallet supply, and the length of time it takes these factors to impact supply. The names of variables used to represent the factors are in parentheses

Factor	Impact of factor	Impact time
Price of pallets (pallet price)	Positive	Immediate
Regional price of low-grade lumber (lumber price)	Negative	3 to 6 quarters
Wage rates in the pallet industry (suppliers' wage rates)	Negative	3 to 6 quarters
Index of labor productivity in the pallet industry (index of productivity)	Positive	3 to 6 quarters

The impact time associated with a change in wage rates relative to interest rates (the wage rate/interest rate ratio) is lengthy because of the time it takes to recognize the potential of palletizing, develop a palletized handling system, and implement such a system. We assume that it takes potential pallet users 1 year to recognize the need for a pallet system, another year to plan for a materials handling system that uses pallets, and a third year to implement the system.

The impact time period associated with lumber price, wage rates, and labor productivity variables in the supply equation is 3 to 6 quarters. Work by Schuler and Wallin (1983) and Luppold (1984) has indicated that past input prices affect current pallet production. The length of time it takes pallet producers to react to changes in prices results from a number of factors, including the tendency of pallet firms to stockpile materials and price inventories on a first-in/first-out basis. Because many pallet producers tend to inventory lumber, past lumber price affects current pallet supply. Another factor that causes delayed responses in pallet production after a change in production costs is the lack of precise day-to-day data on the cost of production and net revenue.

Statistical Results

The statistically estimated regional demand and supply equations are shown in Tables 3 and 4, respectively. All dependent and independent variables were transformed by taking the natural logarithm, resulting in equations of multiplicative form.

The estimated demand equation fitted the data well; the multiple correlation coefficients (R^2's) ranged between 0.79 and 0.94. The signs of all coefficients in all regional equations were as expected—coefficients associated with output price and the labor/capital ratio were positive and the coefficients associated with pallet price and wage rates were negative. The coefficients associated with pallet price, output price, wage rates, and the ratio of wage rates to interest rates were significant across all regions at the 0.05 alpha level or higher.

The estimated supply equation also fitted the data well; the R^2 ranged between 0.86 and 0.97. Again, the signs of all supply equation coefficients were as expected—the coefficients associated with pallet price and the labor productivity index were positive and the coefficients associated with lumber price and wage rates were negative. The coefficients associated with all variables in the eight supply equations were significant at the 0.05 alpha level or higher, except for the coefficient associated with lumber price in the Pacific Region. The insignificant coefficient associated with lumber price in the Pacific Region probably resulted from the fact that no satisfactory lumber price series could be found to reflect the type of lumber used by western pallet manufacturers.

The Durbin Watson (DW) statistics indicate some degree of first-order autocorrelation in the South Atlantic supply regions. All other DW statistics fell within the indeterminate area of the DW table. Because autocorrelation is an efficiency problem and the individual coefficients of the South Atlantic supply equation are statistically significant, no adjustment for autocorrelation was completed.

Analysis of Results

The coefficients in Tables 3 and 4 were estimated to allow direct interpretation. The technical name for these coefficients is elasticities. An elasticity represents the percentage impact on a dependent variable (in this instance, pallet usage or production) caused by a 1-percent change in an independent variable (the variables outlined in Tables 1 and 2). Elasticities are useful because they provide information on the relative importance of a particular factor on demand or supply. For example, if the price of pallets were increased by 1 percent, the demand for pallets in the New England Region would decrease by 1.23 percent. Likewise, if the price of output increased by 1 percent in the New England Region, pallet demand would increase by 5.26 percent.

In Table 3, the size of the output price elasticity compared to the other price elasticities indicates that output price tends to heavily influence pallet demand. A strong gain in pallet demand tends to be linked to periods of high economic activity, while slumps in the pallet market correspond to low economic activity.

The second most influential variable affecting pallet demand, as indicated by the coefficients in Table 3, is wage rates in the industries demanding pallets. The wage-rate elasticity of demand is higher than the pallet-price elasticity of demand in every region where the coefficient associated with wage rates is statistically significant (valid).

The coefficient associated with the ratio of wage rates to interest rates is difficult to interpret. However, this variable indicates that capital is substituted for labor as the relative cost of capital decreases in relation to the relative cost of labor. The rather small coefficient and length of the reaction time associated with this variable indicate that this substitution occurs slowly.

Table 3.—Results of the demand equation estimation, by region

Region	Price output	Pallet price	Wage rates	Wage/interest ratio	R^2	DW
New England	5.26 (3.85)	-1.23 (-4.86)	-3.90 (-3.50)	0.50 (9.93)	0.82	1.56
Mid-Atlantic	5.21 (5.83)	-1.40 (-7.18)	-1.93 (-4.42)	0.53 (12.39)	0.94	1.51
East North-Central	3.59 (2.10)	-1.27 (-5.62)	-2.60 (-2.72)	0.38 (8.68)	0.79	1.28
West North-Central	5.71 (2.89)	-1.14 (-2.96)	-3.93 (-2.44)	0.66 (9.36)	0.87	1.19
South Atlantic	3.34 (3.79)	-1.22 (-6.63)	-1.87 (-2.79)	0.49 (11.79)	0.89	1.46
East South-Central	3.76 (2.95)	-1.36 (-5.45)	-3.00 (-2.84)	0.49 (10.41)	0.84	1.33
West South-Central	3.40 (2.78)	-1.15 (-4.19)	-1.93 (-1.97)	0.53 (10.41)	0.88	1.53
Pacific	4.71 (3.32)	-1.02 (-3.64)	-3.43 (-2.96)	0.48 (9.49)	0.84	1.48

t values are in parentheses.
t = 2.479 at 0.01 level of significance.
t = 1.706 at 0.05 level of significance.

Table 4.—Results of the supply equation estimation, by region

Region	Pallet price	Lumber price	Wage rates	Productivity index	R^2	DW
New England	1.98 (12.0)	-0.80 (-4.46)	-0.85 (-2.91)	1.62 (4.36)	0.89	1.19
Mid-Atlantic	2.07 (16.6)	-0.52 (-6.23)	-0.58 (-3.12)	1.53 (5.82)	0.97	1.13
East North-Central	2.06 (17.6)	-0.78 (-10.01)	-1.23 (-7.07)	1.45 (5.89)	0.92	1.39
West North-Central	2.45 (13.2)	-0.22 (-1.82)	-1.37 (-4.94)	2.29 (5.84)	0.95	1.44
South Atlantic	1.86 (13.0)	-0.61 (-6.46)	-0.72 (-3.39)	1.05 (3.49)	0.91	1.01
East South-Central	2.34 (17.9)	-0.83 (-9.59)	-1.66 (-8.52)	1.53 (5.55)	0.92	1.40
West South-Central	2.25 (13.2)	-0.65 (-5.76)	-0.71 (-2.77)	1.27 (3.53)	0.93	1.37
Pacific	1.52 (4.96)	0.02 (0.005)	-1.12 (-3.11)	1.68 (4.08)	0.86	1.08

t values are in parentheses.
t = 2.462 at the 0.01 level of significance.
t = 1.699 at the 0.05 level of significance.

Pallet price elasticity of demand is near or below 1 in every region, indicating that the demand for pallets is relatively insensitive to changes in pallet price. The fact that the demand elasticities of factors that are determined outside of the pallet market—output price and wage rates—are larger than pallet price elasticity indicates that general economic forces influence pallet demand more so than forces within the pallet market.

The information in Table 4 indicates that pallet price is the single most influential factor affecting pallet supply. The relative value of pallet-price elasticity to lumber-price elasticity and wage-rate elasticity indicates that, unlike pallet demand, pallet supply is very much affected by forces within the pallet market. In fact, in all but the East South-Central Region, the pallet-price elasticity of supply exceeded the sum of the lumber-price and wage-rate elasticities of supply.

Wage-rate elasticity of supply and lumber-price elasticity of supply are very similar for half of the regional supply equations. There seems to be a marked difference between the central regions and eastern regions. The one exception to this rule is the West South-Central Region, which is primarily the state of Texas. Since the central regions are associated with heavy industry and a large degree of unionization, it is expected that the larger wage-rate elasticity of supply is a result of the degree of unionization in the central regions.

The index representing changes in labor productivity on the supply of pallets indicates that a great deal of labor-saving capital investments occurred in the pallet industry during the last 10 years. This degree of labor productivity is indicated by the fact that employment in the pallet industry increased by 42 percent between 1975 and 1983, while pallet production has increased by 62 percent.

Regional differences were observed in the magnitude of some of the estimated elasticities. For example, pallet users in the industrialized regions of the North (New England, Mid-Atlantic, and West North-Central) were more sensitive to changes in output price than pallet users in other regions. In the industrial North, the pallet-using industries are concentrated in the primary and fabricated metal manufacturing and machinery manufacturing areas. These industries may be sensitive to the general economic climate and adjust their pallet purchases with each change in the economy.

Price elasticity of supply for pallets is relatively large in all regions. Pallet producers are expected to adjust levels of production rather quickly in response to changes in the market price of pallets. To be competitive, some pallet producers must adjust their levels of production by entering or leaving the market.

Summary and Conclusions

Eight regional demand and supply equations were developed in this study. In these equations, pallet demand is developed as a function of the prices of the demander's inputs used with pallets and the price of the pallet demander's output, and pallet supply was developed as a function of the prices of inputs used in the pallet production process and the price of pallets.

The results of these equations indicate that significant variation exists in pallet demand and supply in the eight different regions. Regional equations can be considered as opposed to a national equation that would ignore regional variation. The estimated demand and supply equations fitted the data well—the R^2 ranged from 0.76 to 0.97. Estimates of output-price elasticity, wage-rate elasticity of demand, and pallet-price elasticity of supply indicate that these are major factors influencing the quantities of pallets in each of the regional markets.

In the demand equations, output-price elasticity is always larger than either of the input elasticities, that is, the wage-rate or pallet-price elasticities. In six of the eight regions, output-price elasticity is also larger than the sum of these two input-price elasticities. Additionally, the wage-rate elasticity of demand is generally higher than pallet-price elasticity. As noted before, output price and pallet demanders' wage rates are determined outside the pallet market. Thus, general economic forces that determine the level of these variables have a greater effectd on the pallet demand than the effect of forces within the pallet market.

In the supply equations, the relative magnitude of the pallet-price elasticity in comparison to input-price elasticities for lumber price and wage rates indicates that, unlike pallet demand, pallet supply is very much affected by forces within the pallet market. As noted earlier, in all but one region, pallet price elasticity is larger than the sum of lumber-price and wage-rate elasticities. Thus, pallet price exerts a greater influence on the quantity of pallets supplied than the other forces within the pallet market.

The analysis shows that differences exist among regions with respect to pallet demand and supply. Factors that influence these differences include pallet price, price of outputs, and wage rates of pallet demanders. This analysis should provide a sound basis for future assessments of regional pallet demand, supply, and price.

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Appendix A

Demand and Supply Equations

Demand Qd = f(PO, PPID3, ED3, EID4)
Supply Qs = g(PPI, PLUD2, PLSD2, ILPRD2)

where:

Qd =	Regional quantity of pallets demanded in quarter t.
Qs =	Regional quantity of pallets supplied in quarter t.
PO =	Weighted regional producer price indexes for industries that use pallets. Source of price indexes: Bureau of Labor Statistics. Weights used to calculate regional indexes are in Appendix B.
PPID3 =	Pallet price index specified as a polynomial distributed lag t-4 to t-7. Source of price index: Bureau of Labor Statistics.
ED3 =	Weighted regional wage rates for industries that use pallets, specified as a polynomial distributed lag t-4 to t-7. Source of wage rates: Bureau of Labor Statistics. Weights used to calculate regional wage rates are in Appendix B.
EID4 =	Ratio of regional wage rates in industries that use pallets to the interest rate on 90-day commercial paper, specified as a polynomial distributed lag t-9 to t-12. Source of interest rates: Survey of Current Business.
PPI =	Price index of pallets. Source: Bureau of Labor Statistics.
PLUD2 =	Regional price of lumber specified as a polynomial distributed lag t-3 to t-6. Source of lumber prices: Hardwood Market Report. Specific species used in calculating regional lumber prices are in Appendix C.
PLSD2 =	Wage rates in the pallet and wood container industry, specified as a polynomial distributed lag t-3 to t-6.
ILPRD2 =	Index of labor productivity in the pallet industry measured as the value of shipments per man-hour, specified as a polynomial distributed lag t-3 to t-6.

Appendix B

Weights Used to Calculate Regional Indexes for Pallet-Using Industries

Industry	Region							
	New England	Mid-Atlantic	East North-Central	West North-Central	South Atlantic	East South-Central	West South-Central	Pacific
Food	0.07	0.12	0.09	0.21	0.13	0.14	0.17	0.17
Textiles	0.09	0.06	0.00	0.01	0.31	0.11	0.01	0.01
Paper	0.09	0.06	0.04	0.05	0.06	0.06	0.05	0.05
Chemicals	0.04	0.10	0.05	0.04	0.09	0.12	0.12	0.05
Rubber, plastics	0.08	0.06	0.07	0.06	0.03	0.06	0.06	0.06
Stone, clay, glass	0.02	0.05	0.03	0.06	0.06	0.05	0.06	0.05
Primary metal	0.06	0.14	0.13	0.04	0.06	0.10	0.07	0.06
Fabricated metal	0.16	0.13	0.17	0.12	0.07	0.12	0.15	0.13
Machinery	0.24	0.19	0.22	0.27	0.09	0.12	0.19	0.16
Transportation equipment	0.15	0.09	0.20	0.14	0.10	0.12	0.12	0.26

Appendix C

Specific Species Used in Calculating Regional Lumber Prices

Region	Species[a]
New England	Northern red oak (Grades 2C and 3A) and Northern hard maple (Grade 2C)
Mid-Atlantic	Northern red oak (Grades 2C and 3A)
East North-Central	Northern red oak (Grades 2C and 3A)
West North-Central	Northern red oak (Grades 2C and 3A)
South Atlantic	Southern red oak (Grades 2C and 3A)
East South-Central	Southern red oak (Grades 2C and 3A)
West South-Central	Southern red oak (Grades 2C and 3A)
Pacific	Softwood lumber price index, from Fingertip Facts and Figures, published by NFPA, Washington, D.C.

[a]Prices for individual species taken from *Hardwood Market Report* (Lemsky 1972-84), first week in each quarter.

Luppold, William G.; Anderson, R. Bruce. **A regional analysis of pallet supply and demand.** Res. Pap. NE-580. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1986. 8 p.

This paper examines the factors that affect regional pallet supply and demand by developing, estimating, and interpreting models for the eight major census regions with viable pallet markets.

ODC 721

Keywords: Econometric; production; usage

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Allegheny Hardwood Regeneration Response to Even-age Harvesting Methods

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Abstract

Allegheny hardwood regeneration response to block clearcutting, alternate strip clearcutting, and two-cut shelterwood, and in an uncut control was compared. Stand regeneration success was evaluated 5 years after harvest. Clearcutting resulted in high mortality of advance regeneration. Thus, regeneration by block clearcutting was not successful, though both alternate strip clearcutting harvests were successful. The first cut of the shelterwood established new seedlings but did not stimulate growth. Regeneration level increased from inadequate to adequate and remained so after the final harvest. New seedlings appeared in the control after each seed crop, but few survived. Fenced seedlings grew taller in all harvest areas.

Contents

Study Area 1
Regeneration 2
Seed production 2
Environmental factors 2
Cutting methods 3
Analysis of Data 3
Results and Discussion 3
Logging mortality 3
Environmental factors 4
Effect of seed source 5
Initial regeneration differences 5
Effect of treatment on the total number of stems 5
Effect of treatment on regeneration stocking 7
Effect of treatment on stem height 8
Effect of fencing 9
Old versus new seedlings 9
Herbaceous covers 9
Summary and Conclusions 12
Literature cited 12

Cover photo—Fencing to prevent deer browsing allowed seedlings to grow taller. Also, regeneration stocking increased with a greater proportion of desirable species.

The Allegheny hardwood forest consists primarily of black cherry, red maple, sugar maple, and beech.[1] Associated species include white ash, yellow-poplar, sweet and yellow birch, cucumbertree, and hemlock. Many of these species demand light, and some form of even-age silviculture is essential for their regeneration. In the past, this usually meant block clearcutting.

Block clearcutting regenerates relatively large areas when advance regeneration of desired species is adequate. However, advance seedlings are too few or too small in more than two-thirds of all Allegheny hardwood stands (Marquis and Bjorkbom 1982). Clearcutting removes the seed source and provides a harsh environment for the germination and survival of seeds stored in the forest floor. Seed dispersal from adjacent areas is often inadequate. Thus in the absence of advance regeneration, other even-age silvicultural systems, such as shelterwood cutting or alternate strip clearcutting, may be more appropriate.

We studied the effects of these three cutting methods on the survival and growth of advance seedlings and on the establishment and growth of seedlings appearing after cutting. We observed solar radiation, soil moisture, and surface temperature of the forest floor. Also, we noted changes in herbaceous vegetation and determined the impact of deer browsing on tree reproduction by fencing some plots. Both the shelterwood and alternate strip clearcutting methods provided a less harsh environment and successfully regenerated the stands. Fencing in all treatments protected seedlings from browsing, resulting in taller seedlings.

Study Area

This study was on the Kane Experimental Forest in northwestern Pennsylvania. The site is on unglaciated, relatively uniform terrain of the Allegheny Plateau at an elevation of 1,900 feet.

The block clearcutting treatment occupied a 25.6-acre area (16.0 chains by 16.0 chains) on upper flat and midslope positions. Slope averaged 14 percent on a 255 degree aspect. The soils belong to the Hazelton (coarse loamy, mixed, mesic Typic Dystrochrepts) and Cookport (fine loamy, mixed, mesic Aquic Fragiudults) series. These soils, formed in place from the underlying bedrock, have loam to silt loam textures throughout their profiles and range from well to moderately well drained. Dormant season perched water tables occur only at depths exceeding 2 feet.

The shelterwood treatment area covered 6.4 acres (8.0 chains by 8.0 chains) on upper flat and midslope positions. Slope was 13 percent and aspect 194 degrees. The soils here are very similar to those found in the block clearcut.

The alternate strip clearcutting area totaled 3.2 acres among four adjacent strips, each 1.0 chain wide and 8.0 chains long. The strips were oriented in a Northwest-Southeast direction in the upper flat position with a 6 percent slope and a 246 degree aspect. Soils in this treatment are loams and silt loams and belong almost exclusively to the Cookport series. They range from moderately well to somewhat poorly drained. Mottling is quite variable. The dormant season water table occurs at depths between 6 and 24 inches. They are slightly wetter than the soils in the other plots.

An uncut control area of 6.4 acres (8.0 chains by 8.0 chains) on the upper flat had a 9 percent slope and 134 degree aspect. Soil textures are principally loams and silt loams, rarely sandy loam. Mottling was not observed in the first 2 feet of the soil. Soils in this treatment are generally similar to those in the block clearcut and shelterwood treatment plots.

All areas supported fully stocked stands of Allegheny hardwoods ranging in relative stand density from 98 to 104 percent. However, species compositions were not similar and total basal area amounts differed by as much as 35 square feet (Table 1). The basal area of the block clearcut stand totaled 44 square feet per acre with 44 percent in red maple, 27 percent in beech, and only 9 percent in black cherry. In the alternate strip clearcutting area, the total basal area per acre of 162 square feet was principally black cherry (40 percent) with equal amounts (22 percent) of red maple and sugar maple. The total basal area in the shelterwood area was 153 square feet per acre with 52 percent in red maple and 29 percent divided about equally between black cherry and beech. In the uncut control stand, four species—beech, birch, red maple, and sugar maple—accounted for 81 percent of the total basal area (127 square feet). The proportions among those species were roughly similar, ranging from 23 percent beech to 17 percent sugar maple. Black cherry accounted for only 7 percent.

Advance regeneration varied considerably among the treatment areas. Black cherry regeneration was particularly abundant in the alternate strip clearcutting area, which also had the greatest amount of black cherry in the overstory. Red maple seedlings were most abundant in the strip clearcut and shelterwood. Beech was generally quite evenly distributed. Other principal species present were sugar maple and hemlock (Table 1).

Logging to create the block clearcutting, strip clearcutting, and shelterwood treatments began in November 1973 and was completed in January 1974. Subsequently, the shelterwood residual stand and the alternate, previously uncut, strips were then clearcut during May and June 1979. To determine the regeneration and environmental effects of these cutting methods, we observed and measured the advance regeneration, the regeneration that developed after cutting, seed production, soil moisture, surface temperature of the forest floor, solar radiation, herbaceous vegetation, and browsing by deer.

[1]Scientific names of species referred to in this report are listed at the end of this paper.

Table 1.—Selected pretreatment characteristics of the overstory (1972) and the regeneration (Spring 1973) by treatment

Characteristic	Block clearcut	Alternate strip clearcut	Shelterwood	Control
Area, acres	25.6	3.2	6.4	6.4
Relative stand density (percent)	104	100	100	98
Median stand diameter[1]	12.7	13.9	13.3	11.0
Basal area/acre (ft^2)				
Black cherry	13	64	23	9
Sugar maple	9	36	14	22
Red maple	64	36	80	26
Birch	7	2	4	26
Beech	39	14	21	29
Hemlock	8	10	10	<1
Other	4	0	1	15
Total	144	162	153	127
Regeneration:				
Percent stocking	21	84	48	8
Stems/acre (× 1000)				
Black cherry	7.5	141.0	17.6	1.8
Red maple	7.9	21.0	22.5	2.4
Beech	3.6	2.8	2.4	2.4
Other	0.5	1.8	0.2	4.9
Total	19.5	166.6	42.7	11.5

[1]Diameter at the midpoint of the stand basal area.

Regeneration

For estimating the amount of regeneration, we established a pair of 6-foot-radius plots at each of 24 randomly located sampling points in the block clearcut area, at 20 sampling points in each of the shelterwood and control areas, and at 10 sample points in each of the four alternate cut strips. To evaluate the impact of browsing by deer, one plot in each pair was fenced.

A 1.25-chain-wide isolation area surrounding the regeneration sampling area minimized the influence of the adjacent uncut stand on seedling establishment and development in the block clearcutting and shelterwood treatments. However, in the alternate strip clearcutting area, we did not leave an isolation area around the regeneration sampling plots because the shading and seed source effects of adjacent uncut areas are essential attributes of strip clearcutting.

Regeneration inventories were made for each area in the spring of 1973, and at the end of each growing season from 1973 through 1976, and again in 1978. In addition, the regeneration in the shelterwood, alternate strip, and control areas was also inventoried in 1984. Seedlings were recorded by species and by height class as less than 1 foot, 1 to 3 feet, 3 to 5 feet, and greater than 5 feet. To aid in interpreting the effects of treatment, the species occurring in this study were further classified as desirable, commercial, and noncommercial. Desirable species include black cherry, sugar maple, red maple, cucumbertree, and yellow-poplar. Commercial species include beech, birch (yellow and sweet), and hemlock in addition to the desirable species. Noncommercial species are principally pin cherry and striped maple, but also include serviceberry and eastern hophornbeam.

Based on these inventory data, the 6-foot-radius regeneration plots were classed as stocked or not stocked. To be stocked before the final harvest, a plot must contain at least 25 black cherry stems or 100 stems of all desirable species taller than 2 inches. Two to five years after the final harvest, both total number of stems per plot and number of stems taller than 3 feet were considered in determining whether a plot was stocked. Thus, stocking after cutting was calculated as the average of the proportion of plots with at least five stems taller than 3 feet and the proportion of plots with at least 25 stems total. Either before or after the final harvest, regeneration in a stand is considered adequate if at least 70 percent of the sample plots meet these criteria (Marquis and Bjorkbom 1982).

The seedlings present in 1972, and those originating in 1973, 1974, and 1975, were marked each year with a different color. Seedlings becoming established after 1975 were not marked. Thus, it was possible in 1978 to identify those advance seedlings that were at least 2 years old at the time of cutting, those 1 year old at the time of cutting, and the new seedlings that originated during the first, second, and later years after cutting.

Seed Production

Four randomly located seed traps in each treatment area were used to estimate seed production. Each trap was 0.25 milacre in area (3.3 by 3.3 feet). Seed collections were made at the end of the seed dispersal periods during 1973 through 1976.

Environmental Factors

Soil moisture was measured with a nuclear surface moisture gauge at weekly intervals throughout the growing

season from 1973 through 1976. These measurements were made at eight randomly selected points in each treatment.

Surface temperatures of the forest floor were measured with an infrared field thermometer. These measurements were made at 20 randomly selected points in each treatment area (24 in the block clearcutting) at weekly intervals during the growing seasons of 1975 and 1976.

Solar radiation was estimated using an anthracene-benzene chemical light meter (Marquis and Yelenosky 1962). These estimates were made at 20 randomly selected points in each treatment area (24 in the block clearcutting) for a 1-week period during the 1973 and 1976 growing season.

Cutting Methods

The block clearcutting was done as a final harvest cutting method to release advance regeneration present on the site and to stimulate germination of seed lying dormant in the forest floor. The treatment consisted of cutting all trees in the 2-inch and larger diameter classes. However, only 21 percent of the regeneration plots in this stand were stocked before treatment (Table 1). Thus, this stand did not meet the established guideline of at least 70 percent stocking for adequate regeneration (Marquis and Bjorkbom 1982).

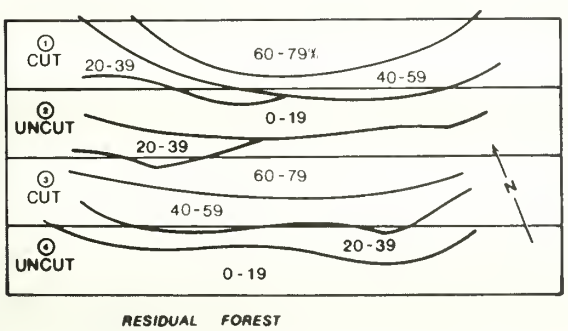

Figure 1.—Percentage of full sunlight at various locations within the alternate strip cutting treatment. August 3 to 13, 1976.

The strip clearcutting was also a final harvest and removed all trees in the 2-inch and larger diameter classes. This treatment differed in that four adjacent 1-chain-wide strips were established but only strips 1 and 3 were cut, leaving the alternate strips 2 and 4 uncut. All cutting and skidding activities were confined within the area cut so as not to disturb the adjacent uncut strips. In this treatment, the narrow clearcuts (1 chain wide) received some shade and possibly seed from the adjacent uncut areas. Conversely, the uncut strips adjacent to the cutting received additional light from the sides thus favoring seedling establishment and growth (Fig. 1). The uncut strips were subsequently cut 5 years later in 1979. All four strips had adequate advance regeneration before cutting with 84 percent stocked plots (Table 1).

When the block clearcut and the clearcut strips were harvested, the shelterwood area received the preparatory harvest, the first of two planned cuts. The objective of the preparatory harvest was to open the stand and thus stimulate seed production on residual trees and increase light reaching the forest floor to favor seedling establishment and development. Advance regeneration was to increase in size and numbers before the final harvest due in 5 years. The first cut removed about 26 percent of the total basal area in trees 4 inches and larger leaving a stand of 69 percent relative density. The larger and best quality stems of desired species at a uniform spacing were retained.

Analysis of Data

Statistical significance in all tests in this study was accepted at the 0.05 level.

Differences in sunlight, soil moisture, and soil temperature were tested by analysis of variance. Percentage data were transformed by arcsine. Differences among individual treatments were compared using Fisher's protected LSD.

The number of stems by species and size class were compared between fenced and unfenced plots within each treatment by a t-test for paired plots. This test was also used for comparing the number of stems by species (fenced and unfenced) in each treatment at the start of the study in 1973 with the number present in 1978.

Because the number of stems by species before cutting was so variable among plots, analysis of covariance was used to test treatment effects on number of stems by height class. The independent variable was the total number of stems in the fall of 1973, and the dependent variable was the number of stems by height class in the fall of 1978. Comparisons among the adjusted means were made using the Bonferroni t statistic (Bailey 1977).

Pin cherry was not present in any treatment area in 1973, therefore, analysis of variance was used to test treatment effects on the number of stems of this species by height class. Treatment means were compared using Fisher's protected LSD.

Results and Discussion

Logging Mortality

Logging generally destroys some advance regeneration. The greatest losses occur when the ground is bare of snow.

Losses are least with a deep snow cover. During the period of logging, snow depth measured 4 inches or less 83 percent of the time (U.S. Dep. Commer. 1973a, b; 1974a)—insufficient to afford much protection.

Seedling mortality due to logging was assumed as the difference between the before and after inventories of regeneration adjusted for the natural overwinter mortality (40 percent) that occurred in the uncut stands. Much of this natural mortality occurred among the numerous red maple germinants that appeared in 1973 but failed to survive in the dense shade of the uncut stands. Natural overwinter mortality of all species in the cut areas also may have been affected by the change in environmental factors resulting from cutting.

The highest logging mortality rate occurred in the block clearcut area (45 percent). The shelterwood plot had the least mortality—11 percent, and the cut strips were intermediate—19 percent of the advance regeneration. High mortality in the block clearcut resulted mostly from the extensive skidding needed to remove the large volume of timber cut, and because of the harsh environment created by the complete exposure of the site. Although the entire overstory was removed in the cut strips as well, mortality was less because the skidding was confined to one trail. Also, the shading effect of the adjacent uncut strips moderated soil and air temperatures, and soil moisture was inherently higher. The shelterwood received only a light partial cut and, although skidding was extensive, continuous use of the same skid trails did not occur. In addition, the residual overstory provided a favorable environment for survival.

Environmental Factors

Solar radiation levels and surface soil temperatures did not differ significantly among the individual treatment areas before cutting. Soil moisture was relatively uniform among the several areas; however, the level in the alternate strip cutting area was somewhat greater than that in the others. After logging, these factors differed substantially among the treatments. Knowing these differences helps to understand and explain the regeneration response to the various treatments.

Solar radiation. Prior to cutting, only about 5 percent of full sunlight filtered through the canopy to ground level—usually considered too little light for adequate seedling growth and only marginal for survival of all but the most tolerant species.

Cutting increased average light levels in the shelterwood and uncut strip treatments. The uncut strip (No. 2) bordered on both the north and south sides by cut strips received an average of 28 percent full sunlight, and the uncut strip bordered only on the north by a cut strip received an average of 13 percent (Fig. 1). The seed cut of the shelterwood treatment increased the light level there to 21 percent. The increased light levels in both the uncut strips and in the shelterwood were expected to result in better survival of advance seedlings and minor stimulation of height growth.

Light levels in the block clearcut and cut strips increased dramatically to 50 to 100 percent of full sunlight. Although these light levels should be near optimum for growth of the intolerant species, they also could produce high surface temperatures and surface moisture stress and thus reduce seedling establishment and survival. The cut strips—especially the south edges—receive partial shade that moderated both temperature and moisture stress (Fig. 1).

Surface temperature. Weekly growing season measurements of the forest floor surface temperature after treatment showed higher temperatures in the block clearcut than in the other treatment areas. However, temperatures in the block clearcut and the cut strips were not significantly different from one another, whereas, differences between the block clearcut and each of the other treatments were significant. Temperatures in the cut strips were often significantly higher than in the shelterwood, the uncut strips, and in the control. Temperatures among the latter three treatments rarely differed significantly (Table 2).

Table 2.—Average surface temperature and range in degrees Celsius by treatment and growing season[1]

Treatment	1975		1976	
	Average	Range[2]	Average	Range
Block clearcut	37c	16–60	37c	13–60
Alternate strip clearcut				
Originally cleared	26cd	9–60	28cd	14–60
Alternate	21d	10–60	24d	13–60
Shelterwood	22d	10–56	25d	13–54
Control	16d	4–31	21d	13–34

[1]Values in the same column followed by the same letter are not significantly different.

[2]Temperatures above 60°C exceeded the maximum limit of the infrared thermometer and were recorded as 60°C.

Surface temperatures of 50 to 54°C (122 to 130°F) often kill young seedlings (Salisbury and Ross 1969). In 1975, soil surface temperatures equalled or exceeded these levels on 8 measurement days from late May to the middle of August and probably killed some seedlings. Usually this occurred at only a few sampling points in any one treatment area but, by the end of July, lethal temperatures had occurred at all sampling points in the block clearcut. This pattern of surface temperatures occurred again in 1976.

Soil moisture. Soil moisture was significantly greater in the cut and uncut strips than in any other treatment in each year of measurement from 1973 through 1976 (Table 3). However, the differences were due to site rather than treatment. The strips occupied an almost level site with some inadequately drained areas where mottling occurred at

Table 3.—Average percentage of soil moisture by treatment and growing season

Treatment	1973	1974	1975	1976
Block clearcut	32b[1]	36b	35b	40b
Alternate strip clearcut				
Originally cleared	34a	45a	44a	46a
Alternate	35a	45a	44a	46a
Shelterwood	30c	37b	38b	40b
Control	31bc	37b	37b	41b

[1]Values in the same column followed by the same letter are not significantly different.

depths of 6 to 24 inches. The other treatment areas were on an inherently drier southwesterly slope with an average depth of mottling in excess of 24 inches.

Soil moisture, as measured by a neutron surface probe used in this study, applies to a relatively large volume of soil. Such measurements do not estimate accurately the soil moisture levels in those crucial areas immediately surrounding either seeds or the rootlets of new germinants. Soil moisture in those micro-environments may have reached critical levels and were not detected. The high surface temperatures experienced in the study areas (Table 2) suggest that evaporation could have contributed to soil moisture reaching critical levels.

Trends in percent moisture by volume for the alternate strips that had the highest moisture content and for the block clearcut that generally had the lowest moisture content are illustrated in Figure 2 for 1973 and 1974. Soil moisture in the

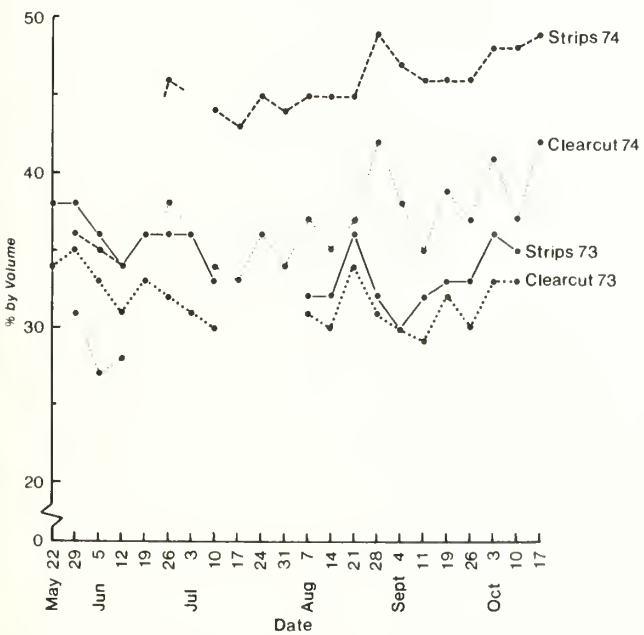

Figure 2.—Trends in percentage of soil moisture in the alternate strip clearcutting and block clearcut areas, 1973 and 1974.

shelterwood area in the control area was not significantly different than that in the block clearcut. Year of measurement seems to have had a greater effect on soil moisture than did treatment. The lowest soil moisture occurred in 1973 when the precipitation from May through October was about 2.4 inches below normal (U.S. Dep. Commer. 1973c); in 1974, the precipitation was about 4.4 inches above normal (U.S. Dep. Commer. 1974b).

Effect of Seed Source

Only in the first year after cutting did new seedlings become established in the block clearcut. These originated from seeds stored in the humus. Thereafter, seed sources were not available and few new seedlings appeared. New germinants appeared in the other treatment areas after each seed year.

Seed traps were maintained in all of the treatment areas from 1973 to 1976, but sizable seed crops occurred only in 1974 and 1975. Most of the collected seeds were red maple (86 percent) and black cherry (7 percent). Red maple seeds were trapped in all treatments though the block clearcutting received only a token number. Black cherry seeds were trapped in all areas except the block clearcut. Seeds of other species dispersed only in small amounts. Because the sample was so small and the amount of trapped seed varied so greatly within each treatment area, differences between areas could not be detected.

Initial regeneration differences

Before treatment, regeneration varied widely in the number of seedlings and in regeneration stocking (Table 1). The alternate strip clearcutting area averaged about 141,000 black cherry stems per acre, many more than in any other treatment. Apparently this abundance occurred because of the large number of seed-producing black cherry and relatively high soil moisture of the site. Although far fewer red maple seedlings were present, they outnumbered those found in the block clearcut and the control areas. The shelterwood area contained more black cherry and red maple seedlings and had a higher regeneration stocking than did either the block clearcut or the control area. These latter treatment areas were very low in numbers of seedlings and percent regeneration stocking.

The pretreatment stocking level of commercial species regeneration observed in the alternate strip, block clearcut, shelterwood, and control areas was 84, 21, 48, and 8 percent, respectively (Table 1). Only in the alternate strip area was stocking greater than the recommended minimum adequate level of 70 percent (Marquis and Bjorkbom 1982). Therefore, this was the only stand suitable for final harvest cutting in 1973.

Effect of treatment on the total number of stems

The total number of stems changed constantly in each treatment area during this study (Table 4). An obvious and expected change occurred the year after logging. The logging itself killed many seedlings. Many others could not survive in the harsh conditions in the cut-over stand. At the

Table 4.—Thousands of stems per acre by species and treatment in Spring 1973, 1974, 1978, and 1984

Species	Year	Block clearcut	Originally cleared strips	Alternate strips	Shelter-wood	Control
Black cherry	1973	7.5	99.0	182.6	17.6	1.8
	1974	.7	49.1	115.2	10.2	1.8
	1978	.9	32.8	137.4	22.2	1.4
	1984	—	—	15.2	7.3	.8
Red maple	1973	7.9	20.4	21.6	22.5	2.4
	1974	4.4	25.6	58.4	51.0	12.2
	1978	1.3	25.2	68.1	96.2	26.6
	1984	—	—	17.0	20.9	3.0
Beech	1973	3.6	2.9	2.7	2.4	2.4
	1974	35.8	10.2	2.7	7.2	3.2
	1978	12.0	2.7	3.7	4.4	4.2
	1984	—	—	2.9	4.0	4.9
Birch	1973	0	0	.1	0	0
	1974	5.4	5.4	1.4	7.8	0
	1978	1.2	3.8	1.6	2.0	0
	1984	—	—	4.4	1.0	0
Pin cherry	1973	0	0	0	0	0
	1974	42.9	3.0	.7	21.2	0
	1978	10.4	1.7	.1	.4	0
	1984	—	—	.3	.6	0
Other	1973	.5	2.7	1.1	.2	4.9
	1974	2.8	1.7	1.1	.5	9.0
	1978	.8	.8	3.4	1.4	5.4
	1984	—	—	1.4	.4	1.5
Total, all species	1973	19.5	125.0	208.1	42.7	11.5
	1974	92.0	95.0	179.5	97.9	26.2
	1978	26.6	67.0	214.3	125.6	37.6
	1984	—	—	41.2	34.3	10.2

same time, because of seedbed disturbance and increased light on the forest floor, newly dispersed seeds as well as viable seeds that had lain dormant in the humus germinated and beech root suckers developed. After the initial surge of new regeneration, changes continued but at a reduced level. Some seedlings died each year as they were crowded out by larger stems. Meanwhile, some new seedlings also appeared after each seed crop, though few of these survived more than 1 year.

Between 1973 and 1978, the number of stems in the cut strips were reduced by almost one-half. Large losses of black cherry during logging were not offset by the development of new stems that occurred elsewhere.

In the same period, regeneration increased by about one-third in the block clearcut. The increase was almost entirely beech root suckers and pin cherry seedlings that appeared the year after cutting. There were significantly more stems of these two species in this treatment than in any other. The pin cherry no doubt are from dormant seed in the floor of the undisturbed forest (Marquis 1975). Many of these germinate in response to the disturbance of heavy cutting. The triggering mechanism of this response may have been the elevated level of soluble nitrogen available in the soil after clearcutting (Auchmoody 1979). Increase in surface temperature after clearcutting, as we observed in this plot, accelerates the rate of organic nitrogen mineralization in forest soils (Theodoru and Bowen 1983).

The total number of seedlings increased slightly during the period 1973 to 1978 in the uncut alternate strips. New red maple germinants accounted for much of the increase. Because no cutting took place, few beech root suckers, birch, or pin cherry became established. By 1984, 5 years after these strips were cut, the total number per acre had decreased greatly with very large reductions in the number of black cherry and red maple seedlings.

In the shelterwood area, the total number of stems increased nearly threefold from 1973 to 1978. Red maple stems accounted for much of the increase as there were significantly more stems of this species here than in any other treatment. Although the number of black cherry stems decreased slightly after the preparatory cut, new cherry regeneration also became established. By 1978, this area contained significantly more black cherry stems than the block clearcut. The partial cutting did not stimulate much beech root suckering. A few birch and pin cherry germinated after the cutting, but not many survived. The number of stems present in 1984 reflect losses due to the logging of the overstory removal and the subsequent losses to increased competition as some stems increased in size.

Although the number of stems nearly tripled in the uncut control area between 1973 and 1978, the number present in 1978 was still much less than that in all other areas except the block clearcut. Red maple seedlings accounted for most of the increase with much smaller increases of black cherry and beech. No birch or pin cherry became established. By 1984, the total number of seedlings in this plot had declined by 1,300 seedlings below the 1973 level, with a 56 percent decrease in black cherry stems and increases of 104 percent in beech stems and 25 percent in red maple stems.

Effect of treatment on regeneration stocking

Between 1973 and 1978, regeneration stocking decreased in the block clearcut and strip final harvest cuttings and increased in the shelterwood and uncut preparatory cuttings. The stocking level of the uncut control area increased during the period 1973 to 1978, but then decreased greatly by 1984 (Table 5). This latter area contained a large number of small, newly germinated red maple seedlings in 1978 that did not survive till 1984.

The block clearcut area did not contain adequate stocking of regeneration before cutting in 1973, and by 1978, 5 years after cutting, it was even lower. This treatment did not successfully regenerate the stand. Stocking also decreased in the clearcut strips but, because of their high initial stocking, they remained satisfactorily stocked. In both these harvest cuts, stocking in 1978 was higher on fenced than unfenced plots.

The percentage of stocked regeneration plots in the shelterwood area increased from an unsatisfactory pretreatment level to a satisfactory level 5 years after the preparatory cut. In 1984, 5 years after the final harvest, stocking was adequate in both the fenced and unfenced plots. However, stocking in the unfenced plots is adequate only if all commercial species are considered, whereas the fenced plots are adequately stocked with desirable species and 100 percent stocked with commercial species. In the alternate uncut strips, initial stocking was high and increased somewhat by 1978. Five years after clearcutting, these strips were still adequately stocked. Fenced plots contained more desirable species than did the unfenced.

Table 5.—Stocking of regeneration by species group and treatment, 1973, 1978, and 1984, in percent

Species group and treatment	Before[1] treatment, 1973	After treatment, 1978		After treatment, 1984	
		Fenced	Unfenced	Fenced	Unfenced
Desirable Species					
Harvest cut:					
Block clearcut	21	13[2]	4[2]	—	—
Originally cleared strips	92	80[2]	62[2]	—	—
Preparatory cut:					
Shelterwood	48	75	90	90[2]	50[2]
Alternate strips	75	85	95	90[2]	80[2]
Control	8	35	35	0	0
Commercial Species					
Harvest cut:					
Block clearcut	21	58[2]	50[2]	—	—
Originally cleared strips	95	95[2]	75[2]	—	—
Preparatory cut:					
Shelterwood	48	85	95	100[2]	70[2]
Alternate strips	78	90	95	95[2]	88[2]
Control	8	40	40	0	0

[1]All plots unfenced at this time.

[2]Five years after final harvest cut. Based on the post cutting criteria; average proportion of plots with at least 25 stems total and 5 stems taller than 3 feet. All others based on precutting criteria; percent of plots with 25 black cherry stems or a total of 100 advance seedlings. Stocking of at least 70 percent is adequate.

Effect of treatment on stem height

Only harvest cuttings stimulated a sizable proportion of the regeneration to more than 1 foot in height in the 5 years after cutting (Table 6). The preparatory cuttings stimulated seedling height growth little in this period. Initially, the most seedling growth occurred on the fenced plots of the block clearcut where they received full sunlight and continuous protection from deer browsing. More than 80 percent of these stems were taller than 1 foot, and more than one-third grew to 5 feet or more. However, a large proportion of these taller seedlings were noncommercial pin cherry. The proportion of taller regeneration was less in the clearcut strips because of the partial shading effect of the adjacent uncut stands. In these strips, about two-thirds of the stems were over 1 foot tall and 1 in 10 was over 5 feet. In 1984, 5 years after final removal, both the alternate strip and shelterwood plots had more than 75 percent of stems taller than 1 foot, and very few of these were noncommercial species. On the unfenced plots in all treatments, the proportion of stems in the taller height classes was much less.

Table 6.—Percentage of commercial and noncommercial stems by treatment and height class, 1978 and 1984.

Height class (feet)	1978					1984[1]		
	Block clearcut	Clearcut strips	Alternate strips[2]	Shelter-wood[2]	Control	Alternate strips	Shelter-wood	Control
COMMERCIAL SPECIES								
Fenced plots:								
<1	17	34	82	91	94	23	17	78
1-3	23	38	15	6	4	19	37	14
3-5	8	14	1	1	<1	15	16	5
>5	4	6	1	<1	<1	37	25	3
Total	52	92	99	98	99	94	95	100
Unfenced plots:								
<1	37	69	91	97	94	54	28	63
1-3	27	26	7	1	4	26	57	25
3-5	4	3	<1	1	2	10	7	8
>5	1	1	<1	<1	<1	9	7	4
Total	69	99	99	99	100	99	99	100
NONCOMMERCIAL SPECIES								
Fenced plots:								
<1	1	<1	1	1	1	1	0	0
1-3	5	0	<1	<1	0	1	1	0
3-5	10	<1	<1	<1	0	1	1	0
>5	32	7	0	0	0	3	3	0
Total	48	8	1	2	1	6	5	0
Unfenced plots:								
<1	8	1	1	1	<1	<1	1	0
1-3	14	<1	<1	0	0	1	<1	0
3-5	5	<1	<1	0	0	0	0	0
>5	4	0	0	0	0	0	0	0
Total	31	1	1	1	<1	1	1	0

[1]Five years after the final overstory removal from the alternate strips and the shelterwood plots.
[2]Preparatory cutting treatments.

In terms of stems greater than 3 feet and 5 feet—criteria of successful regeneration after harvesting—treatment differences were evident 5 years after final harvest. There were significantly larger numbers of stems in these height classes in all species categories, but only in the fenced plots within these treatments. The number of desirable and commercial species in these height classes was favored by those treatments that provide some partial shade before final harvest, the shelterwood and the alternate strips. Tall noncommercial species, mostly pin cherry, developed in each of the harvest cuts with the most in the block clearcut. The number of stems by species, height class, and treatment on fenced and unfenced plots is given in Table 7.

Effect of fencing

Fencing had little effect on the total number of stems during the course of this study (Table 7). The only significant difference between fenced and unfenced plots in total stem number after harvest occurred in the clearcut strip treatment in 1978. The unfenced plots had more than twice as many seedlings as the fenced. These unfenced plots contained very large amounts of black cherry and red maple less than 1 foot tall. In a similar manner, the number of seedlings less than 1 foot tall was significantly greater in the unfenced than in the fenced plots in each harvest treatment. Conversely, the fenced plots in each harvest treatment contained a significantly greater number of taller seedlings than did the unfenced. When protected from browsing, seedlings grow taller and occupy more space crowding out smaller stems, whereas browsed seedlings remain small allowing room for larger numbers.

Regeneration stocking 5 years after final harvest was dramatically higher on the plots protected from deer browsing by fences (Table 5). With the exception of the block clearcut, all harvest cuts contained adequate stocking in desirable species when fenced, and stocking was even higher when all commercial species were included. Although these same treatments resulted in adequate stocking without fencing, the proportion of stocked plots was less and the species composition less desirable. The post-harvest stocking of the block clearcut was inadequate, even with the benefit of fencing. This suggests that deer browsing is not the only factor affecting regeneration. Stocking before cutting was low, logging destroyed much of the advance regeneration, and adequate new regeneration could not survive in the harsh environment created by complete removal of the overstory.

In the preparatory cuttings—the shelterwood and the uncut strips—and in the uncut control where less than optimum light was available, the effect of fencing was much less pronounced. Relatively few seedlings in these areas were taller than 1 foot and rarely did any exceed 3 feet (Table 6). It is possible that the seedlings outside the fences in these areas receiving low light levels were not browsed heavily because the deer were attracted to the nearby clearcuts. Clearcutting results in a flush of new vegetation providing much food. Both the block clearcut and the clearcut strip areas had a large number of new pin cherry (Table 4) and *Rubus* (Table 11) germinants; both of which are favored deer browse. This could have the effect of reducing browse pressure on the uncut and partial cut areas, helping to explain the lack of height difference inside and outside the fences. Also, browsing tends to be limited on small and slow-growing stems. Rapidly elongating seedlings are much more succulent and attractive to deer. In fact, this is partially the idea behind using shelterwood cutting in high-deer-density areas. The preparatory cut encourages the establishment of new seedlings while maintaining slow growth to avoid browsing until the number of seedlings is large enough to overwhelm the deer.

Old versus new seedlings

The old seedlings referred to here are those advance seedlings present in 1973 before cutting. In even-age harvest methods, advance regeneration stems are necessary for successful regeneration. Most of these old seedlings were black cherry, red maple, and beech. The new seedlings are those that became established in 1974 and later.

The number of old seedlings decreased over the study period with the greatest decreases occurring immediately after logging. Survival of these seedlings was lowest in the final harvest cuttings where the effects of logging were greatest and in the uncut control where the low light levels made survival difficult (Table 8).

Despite the mortality of the old seedlings and the establishment of new seedlings, the old seedlings represented a substantial proportion of the total regeneration in 1978 (Table 9). In addition, these seedlings, with their initial height advantage and already well-developed root systems, outgrew the new seedlings. In 1978, a greater proportion of the old seedlings was found in the taller height classes (Table 10).

Herbaceous covers

Hayscented fern, New York fern, short husk grass, and sedge occurred in all treatment areas in 1973, but the percentage of area covered was not great enough to be a regeneration problem (Marquis et al. 1975). Since these species can have an inhibitory effect on regeneration of black cherry and other desirable Allegheny hardwoods (Horsley 1977, Horsley and Marquis 1983), it is important to determine if the cutting methods used in this study may influence the spread of these ferns and grasses.

Prior to logging in 1973, a light fairly uniform fern cover grew throughout the treatment area. This coverage ranged from 8 percent in the block clearcut to 12 percent on the cut strips. By 1978, fern coverage had expanded on all plots except the block clearcut. The largest increase occurred in the shelterwood plot where the percentage of area covered nearly doubled to 20 percent. However, this is still not great enough to be considered an inhibitory problem for regeneration. The reasons for the fern coverage increase are not entirely clear, but considering the site requirements of ferns can be helpful. Both fern species commonly grow in moist, shady places (Fernald 1950). Thus, the least favorable location would be the hot, dry block clearcut and this treatment

area did contain the least amount of fern cover. Conversely, the partial shade from the cut strips and shelterwood treatments is quite favorable. Also, as stated earlier, the cut strip area was moister than the others.

Table 7.—Thousands of stems per acre, by height class, species, and treatment on fenced (F) and unfenced (UF) plots, 5 years after harvest cutting

Species	Height class (feet)	Block clearcut		Clearcut strips		Control		Shelterwood		Alternate strips		Control	
		F	UF	F	UF	F	UF	F	UF	F	UF	F	UF
Black cherry	<1	0.1	0.2	5.6 *	21.6	1.9	0.9	1.4	1.4	1.6 *	3.3	1.1 *	0.3
	1-3	.3	.5	11.0	19.5	.1	0	3.8	4.4	2.1 *	6.3	.2	0
	3-5	.3	.1	3.7	2.2	0	0	1.2	.7	2.4	4.4	0	0
	>5	.2	.1	1.4	.5	0	0	1.6 *	.2	6.5 *	3.8	0	0
	Total	0.9	0.9	21.8 *	43.8	2.0	0.9	8.0	6.7	12.6	17.8	1.3 *	0.3
Red maple	<1	0.6	0.9	7.8 *	36.7	26.6	26.7	4.3 *	6.8	4.0 *	17.9	3.7	2.1
	1-3	.6	.5	3.4 *	1.3	0	0	8.0	13.8	2.4	4.4	.1	0
	3-5	0	0	.9 *	0	0	0	3.9 *	1.0	1.6 *	.4	0	0
	>5	0	0	.3 *	0	0	0	4.0 *	0	3.3 *	.1	0	0
	Total	1.2	1.4	12.3 *	38.0	26.6	26.7	20.2	21.6	11.3 *	22.8	3.8	2.1
All desirables[1]	<1	0.9	1.5	13.5 *	58.4	34.5	31.6	5.7	8.2	5.5 *	21.2	6.7	3.4
	1-3	1.4	1.1	14.5	20.8	.1	0	11.8	18.2	4.5 *	10.7	.3	0
	3-5	.6 *	.1	4.9 *	2.2	0	0	5.1 *	1.7	4.1	4.8	0	0
	>5	.3 *	.1	1.8	.5	0	0	5.8 *	.2	9.8 *	3.9	0	0
	Total	3.2 *	2.8	34.7 *	81.9	34.6	31.6	28.4	28.3	23.9 *	40.6	7.0 *	3.4
Beech	<1	3.3 *	7.7	0.1	0.5	1.8	2.5	0.2	0.8	0.3	0.8	2.3	2.3
	1-3	4.5	5.4	1.2	.8	1.6	1.5	1.0	1.1	.4 *	1.7	1.2 *	2.2
	3-5	1.5 *	.9	.8	.8	.3	.5	.5	.6	.3	.5	.6	.7
	>5	.6 *	.2	.6	.6	.2	.1	1.9	2.0	1.3	.6	.3	.4
	Total	9.9	14.1	2.7	2.7	3.9	4.6	3.6	4.4	2.3	3.6	4.4	5.6
Other commercial[2]	<1	3.4 *	8.6	0.8 *	4.9	1.8	2.6	0.2	1.2	1.4	6.6	2.3	2.2
	1-3	4.6	6.3	1.7	2.4	1.6	1.5	1.2	1.2	1.4	3.0	1.3 *	2.2
	3-5	1.5 *	1.0	1.1 *	.8	.3	.5	.7	.5	.4	.6	.6	.7
	>5	.7 *	.2	.9	.6	.2	.1	3.0	2.0	1.6	.6	.3	.4
	Total	10.2 *	16.1	4.5 *	8.7	3.9	4.7	5.1	4.9	4.8	10.8	4.5	5.5
Desirable and commercial[1,2]	<1	4.3 *	10.1	14.3 *	63.3	36.3	34.2	5.9 *	9.4	6.9 *	27.8	9.0 *	5.6
	1-3	6.0	7.4	16.2	23.2	1.7	1.5	13.0	19.4	5.9 *	13.7	1.6	2.2
	3-5	2.1 *	1.1	6.0 *	3.0	.3	.5	5.8 *	2.2	4.5	5.4	.6	.7
	>5	1.0 *	.3	2.7	1.1	.2	.1	8.8 *	2.2	11.4 *	4.5	.3	.4
	Total	13.4 *	18.9	39.2 *	90.6	38.5	36.3	33.5	33.2	28.7 *	51.4	11.5	8.9
Noncommercial[3]	<1	0.2	2.3	0.2 *	0.5	0.1	0.1	0	0.2	0.2	0.1	0	0
	1-3	1.4 *	3.9	0 *	.2	0	0	.3	.1	.3	.6	0	0
	3-5	2.5 *	1.3	.2 *	0	0	0	.1	0	.2	0	0	0
	>5	8.3 *	1.0	2.8 *	0	0	0	1.1 *	0	1.1 *	0	0	0
	Total	12.4	8.5	3.2 *	0.7	0.1	0.1	1.5 *	0.3	1.8 *	0.7	0	0
All species	<1	4.5 *	12.4	14.5 *	63.8	36.4	34.3	5.9 *	9.6	7.1 *	27.9	9.0 *	5.6
	1-3	7.4 *	11.3	16.2	23.4	1.7	1.5	13.3	19.5	6.2 *	14.3	1.6	2.2
	3-5	4.6 *	2.4	6.2 *	3.0	.3	.5	5.9 *	2.2	4.7	5.4	.6	.7
	>5	9.3 *	1.3	5.5 *	1.1	.2	.1	9.9 *	2.2	12.5 *	4.5	.3	.4
	Total	25.8	27.4	42.4 *	91.3	38.6	36.4	35.0	33.5	30.5	52.1	11.5	8.9

* = Significant difference (0.05) between fenced (F) and unfenced (UF).

[1]Black cherry, red maple, sugar maple, white ash, yellow-poplar, and cucumbertree.

[2]Beech, sweet birch, yellow birch, and hemlock.

[3]Pin cherry, eastern hophornbeam, striped maple, and serviceberry.

Table 8.—Survival of old seedlings[1] by species and cutting method, 1978, in percent

Treatment	Black cherry	Red maple	Beech	All species
Block clearcut	3	1	24	3
Alternate strip clearcut				
Originally cleared strip	27	8	42	19
Alternate strip	38	24	81	34
Shelterwood	35	12	50	16
Control	26	9	65	17

[1]Seedlings present at the start of the study.

Table 9.—Old seedlings[1] as a percentage of total regeneration by species and cutting method, 1978

Treatment	Black cherry	Red maple	Beech	All species
Block clearcut	19	24	8	6
Alternate strip clearcut				
Originally cleared strip	68	20	44	43
Alternate strip	52	29	60	45
Shelterwood	19	10	31	12
Control	33	6	44	13

[1]Seedlings present at the start of the study.

Table 10.—Percentage of old[1] and new seedlings by height class, all treatments and species combined, 1978

Height class (feet)	Old Seedlings	New Seedlings	Total
<1	28	72	100
1-3	75	25	100
3-5	65	35	100
>5	71	29	100
Total	37	63	100

[1]Seedlings present at the start of the study.

Grasses, primarily short husk grass and sedge, covered 3 percent or less of each treatment area in 1973 and, at this low level, did not present a regeneration problem. However, logging disturbance and increased light apparently stimulated the germination of seeds stored in the humus, and grass covers expanded. By 1978, 20 percent of the area in the cut strips was grass-covered—more than in any other treatment. Modest increases occurred in the other areas as well, except in the uncut control which did not change. Thus, grass coverage did increase in response to the cutting but not enough in any treatment area to become a regeneration problem.

Rubus differs from fern and grass in that its presence can be beneficial to regeneration. Numerous *Rubus* seeds germinate after cutting or other disturbance. The seedlings grow rapidly and often dominate a regeneration area for several years. Although it forms a dense canopy, the environment beneath is favorable for seed germination and seedling establishment of tree species. At the same time, it may provide new seedlings some short-term protection from browsing. Not only does the dense *Rubus* cover hide tree seedlings from the deer, but it is also highly desirable browse and the deer eat it instead of the tree seedlings. Further, *Rubus* may interfere with fern and grass (Horsley and Marquis 1983).

The establishment and growth of *Rubus*, not present in any treatment area in 1973, was affected by treatment and—because it was browsed heavily—by fencing. In 1978, the greatest amounts were found in the block clearcut and the cut strips with lesser amounts in the shelterwood and uncut strips. There was no *Rubus* in the uncut control. *Rubus* coverage in the unfenced plots was only a fraction of the amount present on the fenced plots, except in the block clearcut, where dense accumulations of slash may have protected the *Rubus* from browsing. Estimated *Rubus* coverage by treatment and fencing is shown in Table 11.

Other herbaceous plants such as adder's tongue, wood sorrel, violet, partridgeberry, and mosses were also present. The percentage of area covered by these plants was small and changed only slightly between 1973 and 1978.

Table 11.—Percentage of area covered by *Rubus* spp. by treatment, fenced and unfenced plots, 1978[1]

Treatment	Fenced plots	Unfenced plots
Block clearcut	58a	51a
Alternate strip clearcut		
Originally cleared	71a	16b
Alternate strip	25b	7c
Shelterwood	15b	2d
Control	0c	0d

[1]Values in the same column followed by the same letter are not significantly different.

Summary and Conclusions

The results of this study indicate that:

1. Cutting methods such as shelterwood or alternate strip clearcutting provide a moderate environment and avoid the extremes of light and temperature found in a block clearcut. The moderating influences of these methods where the complete overstory is removed in two stages improve establishment and survival but did not stimulate height growth of small seedlings prior to final harvest.

2. Cutting methods influence the amount of new regeneration of seedling origin. After cutting and germination of the cherry seed stored in the humus, no new black cherry seedlings appeared in the block clearcut treatment or the original cleared strips of the alternate strip clearcut treatment. In the shelterwood treatment and in the uncut strips of the alternate strip clearcut harvest treatment, a seed source remained and new black cherry seedlings continued to appear.

   Few maple or birch seedlings became established in the block clearcut because the seed dispersal distance from the surrounding stand was too great to obtain adequate seed distribution. But these seedlings appeared in all other treatments including the originally cleared strips where seed dispersal distance was not too great.

   Pin cherry seed stored in the humus germinated in response to higher light levels and/or increased soluble nitrogen concentration in the soil after cutting. The greatest number of seedlings became established in the block clearcut.

3. Advance regeneration is critical in the block clearcutting method because harvesting removes the seed trees, leaving only those seeds stored in the humus to help regenerate the area. Seeds of other species dispersed into the clearcut were inadequate for successful regeneration.

4. The number of seedlings present at the start of the study decreased during the study. However, advance regeneration accounted for a high proportion of the regeneration greater than 1 foot in height 5 years after harvest.

5. Stands with inadequate advance regeneration (<70 percent stocking) should not be clearcut; rather a treatment that removes only a portion of the overstory such as shelterwood should be used.

6. The new beech regeneration was principally of sprout origin and occurred almost exclusively in areas logged.

7. Fencing to prevent deer browsing allowed seedlings to grow taller as well as allowing regeneration stocking to increase with a greater proportion of desirable species. In particular, fencing made a major difference in regeneration stocking in the block clearcut, whereas regeneration in unfenced areas was nearly a total failure.

8. *Rubus* coverage increased greatly after cutting and the heavier the cutting the more *Rubus*. Fern and grass covers were also more extensive after treatment, though field observations suggest that these covers increased in moist rather than in dry sites within any treatment area. Caution should be used in areas where grass and/or fern coverage exceeds 30 percent.

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COMMON AND SCIENTIFIC NAMES OF TREES AND PLANTS REFERRED TO IN THIS REPORT

Trees:

Ash, white	*Fraxinus americana* L.
Beech	*Fagus grandifolia* Ehrh.
Birch, sweet	*Betula lenta* L.
Birch, yellow	*Betula alleghaniensis* Britton
Cherry, black	*Prunus serotina* Ehrh.
Cherry, pin	*Prunus pensylvanica* L.f.
Cucumbertree	*Magnolia acuminata* L.
Eastern hophornbeam	*Ostrya virginiana* (Mill.) K. Koch
Hemlock	*Tsuga canadensis* (L.) Carr.
Maple, red	*Acer rubrum* L.
Maple, striped	*Acer pensylvanicum* L.
Maple, sugar	*Acer saccharum* Marsh.
Serviceberry	*Amelanchier arborea* (Michx. f.) Fern.
Yellow-poplar	*Liriodendron tulipifera* L.

Herbaceous plants:

Adder's tongue	*Erythronium americanum* Ker.
Fern, hayscented	*Dennstaedtia punctiloba* Michx.
Fern, New York	*Thelypteris noveboracensis* L.
Grass, short husk	*Brachyelytrum erectum* Schreb.
Mosses	*Lycopodium* spp.
Partridgeberry	*Mitchella repens* L.
Rubus (raspberry, blackberry)	*Rubus* spp.
Sedge	*Carex* spp.
Sorrel, wood	*Oxalis montana* Raf.
Violet	*Viola* spp.

Bjorkbom, John C.; Walters, Russell S. **Allegheny hardwood regeneration response to even-age harvesting methods.** Res. Pap. NE-581. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1986. 13 p.

Allegheny hardwood regeneration response to block clearcutting, alternate strip clearcutting, and two-cut shelterwood, and in an uncut control was compared. Stand regeneration success was evaluated 5 years after harvest. Clearcutting resulted in high mortality of advance regeneration. Thus, regeneration by block clearcutting was not successful, though both alternate strip clearcutting harvests were successful. The first cut of the shelterwood established new seedlings but did not stimulate growth. Regeneration level increased from inadequate to adequate and remained so after the final harvest. New seedlings appeared in the control after each seed crop, but few survived. Fenced seedlings grew taller in all harvest areas.

ODC 221.21:221.22:221.1

Keywords: 2-cut shelterwood cutting, alternate strip clearcutting, block clearcutting

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13.78:NE S83

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**Northeastern Forest
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Research Paper
NE-583

1986

Rating Forest Stands for Gypsy Moth Defoliation

Owen W. Herrick
David A. Gansner

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Abstract.

The severity of future defoliation can be estimated from the percentages of basal area in oaks (Quercus), black oak (Q. velutina) and chestnut oak (Q. prinus), and in trees with good crowns, along with the average diameter of the stand. With information on these variables, the defoliation potential of any hardwood forest stand in an approaching gypsy moth (Lymantria dispar) infestation can be rated.

Manuscript received for publication 21 February 1986

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Because the levels of defoliation vary widely within areas infested by gypsy moth, the ability to identify critical locations (i.e., those most likely to suffer heavy defoliation during an infestation) is important to resource management. The purpose of this work is to evaluate the relationship between defoliation and forest stand characteristics and develop guidelines for rating the defoliation potential of forest stands on new frontiers of infestation.

Approach

Measurements have been taken each year since 1978 to monitor and evaluate impacts of the gypsy moth on forest trees in central Pennsylvania. The project (a cooperative venture of the Pennsylvania Bureau of Forestry and the U. S. Forest Service) uses a network of some six hundred 1/10-acre field plots located between Carlisle and State College, Pennsylvania. This was the leading edge of gypsy moth infestation in 1978 when the plots were established, before the stands were infested.

Defoliation Data

Ocular estimates of defoliation for all trees 3.0 inches dbh and larger were recorded each year at peak periods of defoliation (June or July). The percentage of foliage stripped from each tree was estimated to the nearest 10 percent. Defoliation averages ($\overline{DF}$) for each plot were derived from the defoliation estimates for each tree (DF_i), weighted by the tree's diameter squared (D_i^2) to account for differences in tree crown size:

$$\overline{DF} = \sum_{i=1}^{n} D_i^2 * DF_i \; / \; \sum_{i=1}^{n} D_i^2$$

Average defoliation on each plot was used to assign it to a light (<30%), moderate (30-59%), or heavy (60+%) defoliation category each year (Gansner and Herrick 1985). The peak year for defoliation was 1981; nearly half the plots had moderate or heavy defoliation that year, and plot defoliation averaged 39 percent (Fig. 1). The next highest defoliation years were 1980 and 1982, with averages at 17 percent and 22 percent, respectively. One-fourth of the plots had heavy defoliation at least once during these 3 years (only 2 percent received as much as 2 years of heavy defoliation). Another third of the plots received moderate defoliation at least once.

The bulk of gypsy moth defoliation activity in central Pennsylvania occurred during the 3-year period from 1980 to 1982. To make allowance for the progressive but uneven nature of gypsy moth infestations we averaged each plot's defoliation measurements for these 3 years. Clearly, more locations in a sample area are likely to be defoliated sometime during several years of gypsy moth buildup than in any single year. Thus, the 3-year average provided a more comprehensive measure of defoliation at any one location during the outbreak.

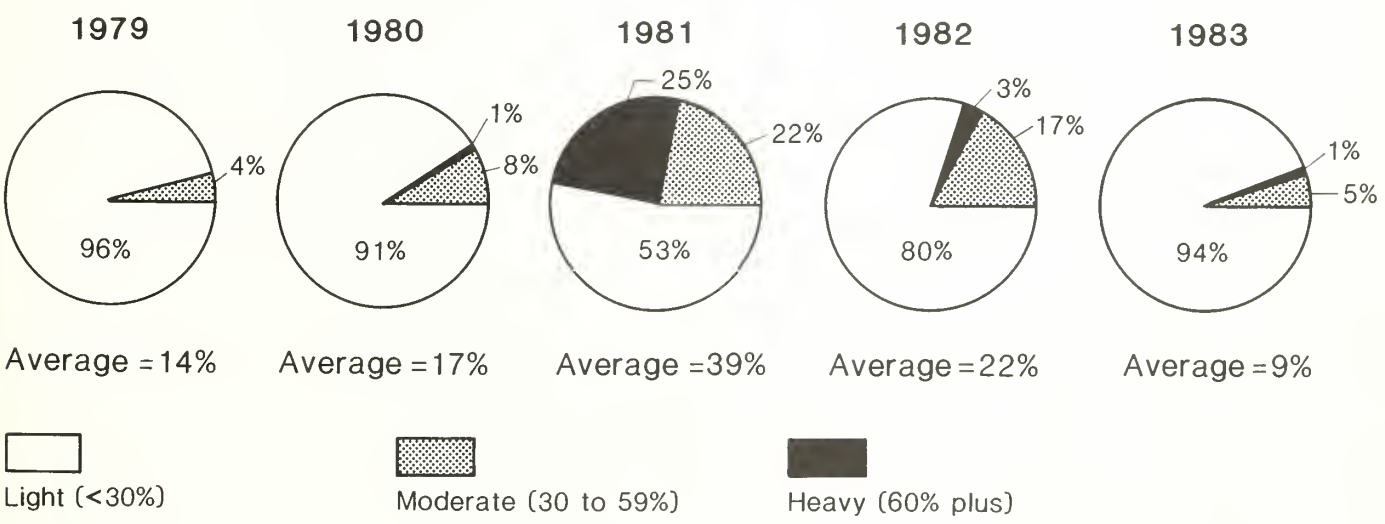

Figure 1.--Gypsy moth defoliation in central Pennsylvania, 1979-83.

Predictor Variables

Many forestland characteristics are potential candidates for gauging the amount of defoliation an area is likely sustain in an infestation. Tree species, size, crown condition, crown position, stocking density, site quality, elevation, and aspect are some prominent attributes that many people associate with gypsy moth defoliation (Bess et al. 1947, Campbell and Sloan 1977, Campbell 1979). More detailed data, such as the prevalence of bark flaps and rock outcrops and egg mass viability may be useful as well (Houston and Valentine 1977, Wilson et al. 1981). As a practical matter, however, only easy-to-measure timber stand characteristics that would be useful in prediction were entered into our analyses. It would be of little help in planning, for example, to have to rely on predicting weather conditions during an infestation to gauge potential defoliation. Also, it is assumed that some indicator of imminent infestation has raised enough concern to warrant rating an area; e.g., to identify forest areas that are candidates for treatment because of their likelihood of being defoliated to unacceptable levels.

The data-plot network covers a full range of values representing preoutbreak conditions (1978) in the infested area. Selected plot variables provide a general description of the coverage area:

	Mean	Range
Basal area/acre (ft^2)	90	15-190
Basal area in oaks (%)	68	0-100
Basal area in black and chestnut oaks (%)	47	0-100
Basal area in dominant and codominant trees (%)	77	14-99
Basal area in trees with good crown condition[1](%)	55	0-100
Average dbh (inches)	7.4	3.8-13.4
Site index (ft., upland oaks)	61	25-100
Stand age (years)	71	15-175
Trees/acre (no.)	255	80-650
Stocking (%)	81	20-158
Slope (%)	24	0-67
Elevation (ft.)	1535	575-2450

[1]A good crown is healthy, with few dead branches and normal foliage density, color, and size.

Analysis

The combined influence that 38 variables have on the 3-year defoliation average was studied by Automatic Interaction Detection (Sonquist et al. 1973). This statistical technique searched characteristics of the trees and timber stands for the best predictors of defoliation. Starting with the entire sample in one group, the plots were partitioned through successive two-way splits into a series of subgroups. The splits occur so that, at each step, the chosen predictor variable forms two new groups that cause the greatest reduction of variance in the dependent variable (average defoliation). The result is a set of best predictors selected by the AID algorithm, and presented as a branching diagram that details the configuration of 3-year defoliation averages from forest stands subjected to the gypsy moth episode in central Pennsylvania.

Results

From 1980 through 1982, the 3-year defoliation average was 26 percent, with a range from 0.3 percent to 70 percent. Plots that were heavily defoliated in any of the 3 years averaged 43 percent. The 3-year average was 27 percent for plots with no more than moderate defoliation; for plots that had only light defoliation, it was 14 percent.

Automatic interaction detection analysis of the 3-year defoliation averages generated 10 final classification groups and the average defoliation percentage for each group (Fig. 2). Each sample plot is a member of one of the groups. Only four of the many tree and timber stand characteristics analyzed as predictor variables were retained in this defoliation classification system: percentage of basal area in oaks, percentage of basal area in black and chestnut oaks, percentage of basal area in trees with good crowns, and average diameter of the stand.

Forest stands represented by the sample plots in the group with the highest average defoliation--40 percent, as compared to 26 percent for the total sample--are identified as Group 1. They have at least 80 percent of their basal area in oak species, at least 70 percent of their basal area in black and chestnut oaks, and at least 60 percent of basal area in trees with good crowns. This group comprised 10 percent of the total sample.

The average defoliation dropped to 31 percent if a timber stand met the first two criteria for Group 1 but had less than 60 percent of its basal area in trees with good crowns (Group 2). Average defoliation was 32 percent when 50 to 79 percent of basal area was in oak species, at least 40 percent of the basal area was in black and chestnut oaks, and at least 40 percent of the basal area was in trees with good crowns (Group 5). These three groups with the highest defoliation averages included 38 percent of the sample. On the

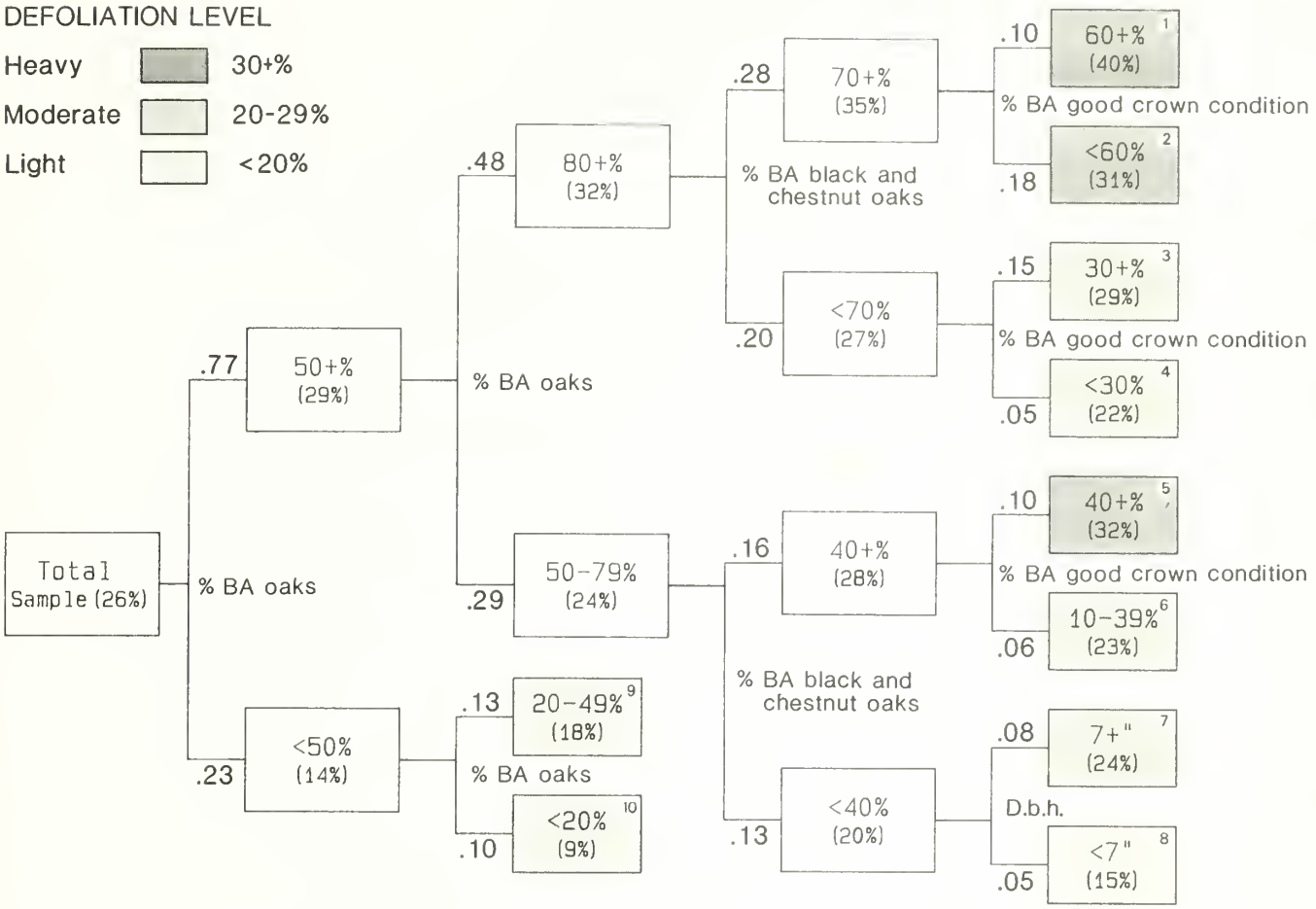

Figure 2.--Guide for estimating gypsy moth defoliation potential. Any hardwood stand can be assigned to a defoliation group on the basis of characteristics of the stand. The 3-year average defoliation percentage is shown in parentheses for each group. Fractions on each line between groups show the portion of the Pennsylvania sample that is in that group.

other hand, as testimony to the strength of host species as a key indicator, stands with less than 20 percent of their basal area in oak species had the lowest defoliation average--9 percent (Group 10).

This study describes a fairly simple structure that can be used to assign potential rates of defoliation to forest stands. It is likely to be most accurate when applied to areas with stand characteristics similar to those of the central Pennsylvania study area. Nevertheless, it is the only available model that links defoliation severity to key forest stand characteristics as predictor variables. Of the many elements of stand condition analyzed as independent variables, the four retained in the model make good sense. Oaks are a favored food of gypsy moth, and black and chestnut oak are highly preferred (Gansner and Herrick 1985); thus species is a strong indicator of stand attractiveness for gypsy moth activity: over half the group-identifying splits in the model were keyed to species alone. Trees with good crowns support abundant foliage which presents attractive insect feeding sites. Likewise, large-diameter trees often support large dominant crowns that are attractive gypsy moth feeding sites.

Perhaps the model's most useful contribution lies in making it possible to separate stands at risk of heavy defoliation from those where defoliation is likely to be light. From the distribution of the 3-year averages we have arbitrarily defined heavy defoliation as above 30 percent and light defoliation as less than 20 percent (Fig. 2). The model gives a basis for rating and mapping the potential severity of forest defoliation. Once the stands are rated, management decisions can be directed toward protecting highly valued forest resources among those identified as most threatened with defoliation in an approaching gypsy moth infestation.

This model's performance will be further validated as the gypsy moth invades new territory. Meanwhile, we are developing measurements that will describe tree mortality and changes in stand condition on this same plot network. These data will be the basis for impact analyses to provide further understanding of defoliation and subsequent tree mortality and loss relationships in forest stands infested by gypsy moth. As was the case in this study, the entire sequence of analyses will focus on the development of more effective guides to help forest resource managers cope with the pest.

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Herrick, Owen W.; Gansner, David A. **Rating forest stands for gypsy moth defoliation.** Research Paper NE-583. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1986. 4 p.

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ODC 453.441: 461.11

Keywords: Hazard classification; defoliation susceptibility; Lymantria dispar

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Research Paper NE-586

1986

Reduce Dimension Costs by Using WALNUT

David G. Martens

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=======>  WALNUT  <============================ Data Entry ==========

   /    /                                              Walnut
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   Date                Name of Cutting Order          Species      Thickness


                                  Lumber Grade Information
                                     (Select only three)
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Cost ($ M bf)
                           ----.--     ----.--     ----.--      ----.--

Yield Adj.
(percent)                   ---.-       ---.-       ---.-        ---.-

Volume Constraints
  (M bf)                   ---.---     ---.---     ---.---      ---.---


 PF1 = Help      PF3 = Exit      PF7 = Prev. screen      PF8 = Next screen
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The Author

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Abstract

A computer program called WALNUT is described that determines the least-cost combination of lumber grades required to produce a given cutting order of walnut furniture dimension parts. If the least-cost mix is not available, WALNUT can be used to determine the next best alternative. The steps involved in using the program are described.

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American black walnut has long been a favorite species for furniture in this country. However, increasing demand for fine furniture and decreasing supplies of high-quality walnut lumber have made prices skyrocket. As a result, furniture dimension manufacturers making walnut parts have been caught in the middle of a cost-price squeeze.

To help alleviate this situation, a computer program called WALNUT has been developed that determines the least-cost mix of walnut lumber grades required to produce a given dimension cutting order. Through linear programing techniques, WALNUT correlates the cost associated with each grade of lumber with the predicted yields of each cutting size obtainable from that grade to arrive at the combination with the lowest total cost. The program is easy to use and can be quickly adapted to fit most furniture rough mills and dimension manufacturing operations.

Data Entry

Input to the WALNUT program is accomplished using the Data Entry screen shown in Figure 1. For future reference, the date, name or model number of the cutting order, and the thickness of the lumber required are entered. The input factors used by the program include the cost per thousand board feet (M bf) associated with each grade of walnut to be considered in the possible least-cost mix, any adjustments desired in the predicted yields for each grade, and any volume constraints to be placed on the grades.

The cost of each grade should represent the sum of all costs associated with that grade through the rough mill. Cost items to be included are at the discretion of the user but could include those for lumber purchase, delivery, drying and handling, rough-mill cutup, inventory, and overhead.

The yield adjustment factor can be used to adapt the basic yields for admissible defects, heavy thicknesses of lumber, or general rough-mill efficiency. The yield values used in WALNUT are derived from nomographs published in USDA Forest Service Research Paper FPL-162 entitled "Dimension Yields From Black Walnut Lumber." The actual numerical yield values and the width adjustments for Firsts and Seconds (FAS), Selects (SEL), No. 1 Common (1C), and No. 2 Common (2C) are extrapolated from Tables 3-10 (Appendix). The yields for each length within a grade are based on the longest length obtained from that grade and are expressed as the net board feet of parts available per M bf of rough lumber input. Consequently, you can place a decimal after the second digit and consider them percentage yields. Yields are for random-width cuttings of 1 inch or wider. Yields for specific widths are obtained by subtracting the appropriate width adjustment from the random-width yields.

Although the WALNUT program can accommodate lengths from 10 to 96 inches and specified widths up to 5½ inches, the length limitations differ for individual grades of walnut lumber. As shown in the yield tables, the longest length available is 96 inches from FAS, 90 inches from SEL, 80 inches from 1C, and 70 inches from 2C.

The volume constraints factor is used to limit the amount of a grade being considered. The resulting evaluation may or may not use all of the grade in limited supply, but in no case will the least-cost grade mix contain more of that grade than the volume allowed. This feature of the program is generally used in determining next best alternatives.

```
=======>  WALNUT  <============================ Data Entry ==========

   /   /                                              Welnut
--  --  --     ------------------------------                    --
   Date              Name of Cutting Order            Species      Thickness


                                  Lumber Grade Information
                                    (Select only three)
Input
Factors
                              2C          1C          SEL         FAS

Cost ($ M bf)
                          ----.--     ----.--     ----.--     ----.--

Yield Adj.
(percent)                  ---.-       ---.-       ---.-       ---.-

Volume Constraints
  (M bf)                  ---.---     ---.---     ---.---     ---.---


 PF1 = Help      PF3 = Exit      PF7 = Prev. screen      PF8 = Next screen
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Figure 1.—Data Entry screen.

Cutting Order

Once the grades and costs have been established, the individual sizes of pieces to be obtained are entered using the Cutting Order screen (Figs. 2-3). Each size of cutting is entered by length, width, type, and number required. WALNUT can accommodate 50 sizes of cuttings or panels. An R is entered for panels that will be glued up from random-width pieces. An S is entered when each part is to have a specified width.

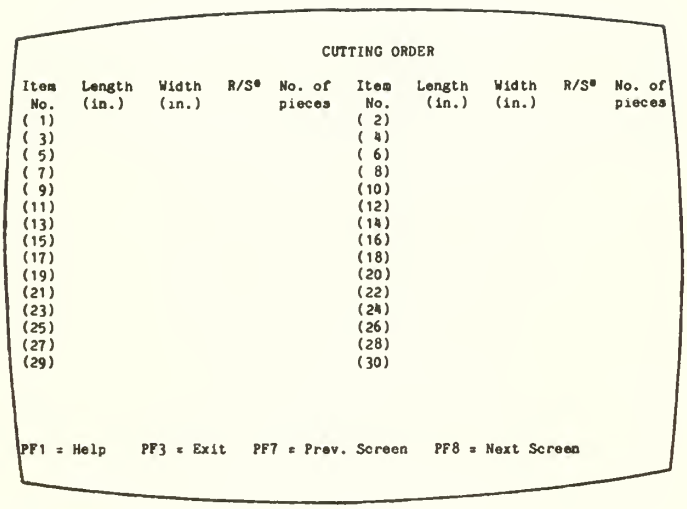

CUTTING ORDER
Item No. Length (in.) Width (in.) R/S* No. of pieces Item No. Length (in.) Width (in.) R/S* No. of pieces
(1) (2)
(3) (4)
(5) (6)
(7) (8)
(9) (10)
(11) (12)
(13) (14)
(15) (16)
(17) (18)
(19) (20)
(21) (22)
(23) (24)
(25) (26)
(27) (28)
(29) (30)
PF1 = Help PF3 = Exit PF7 = Prev. Screen PF8 = Next Screen

Figure 2.—Cutting order (screen 1).

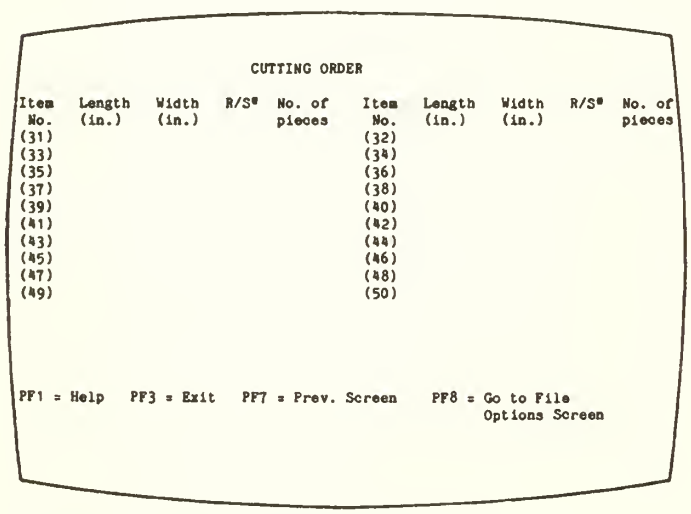

CUTTING ORDER
Item No. Length (in.) Width (in.) R/S* No. of pieces Item No. Length (in.) Width (in.) R/S* No. of pieces
(31) (32)
(33) (34)
(35) (36)
(37) (38)
(39) (40)
(41) (42)
(43) (44)
(45) (46)
(47) (48)
(49) (50)
PF1 = Help PF3 = Exit PF7 = Prev. Screen PF8 = Go to File Options Screen

Figure 3.—Cutting order (screen 2).

WALNUT Printout

The WALNUT printout consists of four sections: (1) the input information that was evaluated, (2) the least-cost grade mix, (3) the range and sensitivity analysis, and (4) the cutting instructions to obtain the desired cuttings.

Input Information

The first section is to be retained for future reference. It provides a record of the information that was on the Data Entry and the Cutting Order screens.

Least-Cost Grade Mix

The second section provides the least-cost grade mix solution (Table 1). For each grade of lumber, the printout shows the predicted lumber volume required, the grade's contribution to the total production cost, the net board feet of cuttings to be obtained from it, the percent yield, and the totals of these items for the entire cutting order.

For the costs and conditions we have specified, this solution represents the best that we can do. There is no other combination of grades and volumes that will result in a lower total cost.

Range and Sensitivity Analysis

The range and sensitivity analysis (Table 1) is the key to using WALNUT as a decisionmaking tool. It indicates how good our current least-cost grade mix is relative to the next best alternatives. As such, it also indicates how we might allocate our lumber when conditions are less than optimal.

The range and sensitivity analysis shows the range over which the input cost of each grade can move without changing the least-cost grade mix, assuming that the input cost of the other grades remains constant. By varying the input cost of one grade while holding the others constant, the program determines at what level of input cost there would be a change in how the grades are used to obtain the cuttings required. The "associated gross volumes" column lists the volume of the grade that would be used at that input cost.

In Table 1, it can be seen that if the input cost of 1C dropped by $1.66 per M bf to $1,108.34, the volume of 1C used in the alternative least-cost mix would increase by 45 percent to 5.500 M bf. Since the alternative mix must have the same total cost as our current least-cost mix, it stands to reason that if more 1C lumber is used in the solution, it must use less of at least one of the other grades. By examining the associated gross volumes shown for the other grades, you can determine that at the lower input cost for 1C, no FAS would be used and the amount of 2C would be reduced to 13.974 M bf. Proof can be obtained by comparing the total cost of our current grade mix with that of the alternative mix for the input cost conditions in this example. Total costs would be:

	FAS	1C	2C	Total
Current	($1,792 × 0.656) +	($1,108.34 × 3.798) +	($575 × 15.210)	= $14,131
Alternative	($1,792 × 0) +	($1,108.34 × 5.500) +	($575 × 13.974)	= $14,131

With this knowledge, the manager could choose the alternative grade mix under current cost conditions, eliminating the need for FAS lumber. The alternative mix would increase the total cost only by about $3 ($14,140 compared to $14,137, as shown in Table 1).

For a more complete discussion of the interpretation of the range and sensitivity analysis and how it can be used as a decisionmaking tool, see USDA Forest Service Research Paper NE-563 entitled "OPTIGRAMI: Optimum Lumber Grade Mix Program for Hardwood Dimension Parts."

Cutting Instructions

The last section of the WALNUT printout is the cutting instructions (Table 2) for obtaining the required furniture cuttings from the proposed least-cost mix. This section is normally given to the rough-mill foreman for use in assigning lengths to specific saw operators.

Table 1.—Least-cost grade mix solution (Nov. 30, 1985: china cabinet No. 7335—walnut)

Selected grade	Input Cost/ M bf	Gross volume	Total production cost	Board feet of cuttings	Percent yield
	Dollars	*M bf*	*Dollars*	*Number*	
No. 2 Common	575	15,210	8,746	7,141.8	47.0
No. 1 Common	1,110	3,798	4,216	2,267.2	59.7
First and Seconds	1,792	656	1,174	483.5	73.7
Total		19,664	14,137	9,892.5	50.3

RANGE AND SENSITIVITY ANALYSIS

Selected grade		Input cost and levels/M bf	Associated gross volumes
		Dollars	*M bf*
No. 2 Common	Upper	577.28	13,974
		575.00	15,210
	Lower	571.78	15,438
No. 1 Common	Upper	1,112.36	3,487
		1,110.00	3,798
	Lower	1,108.34	5,500
First and Seconds	Upper	1,796.31	0
		1,792.00	656
	Lower	1,785.88	775

Table 2.—Optimum solution cutting information (Nov. 30, 1985: china cabinet No. 7335—walnut)

Gross volume	Cutting size		Type of cutting[a]	Cuttings	Net board feet	Board feet shorts
	Length	Width				
M bf	------- *Inches* ------			---------- *Number* ----------		
			NO. 2 COMMON[b]			
15,210	36.750	22.000	R	142	797.3	517.1
	22.750	22.000	R	86	298.9	
	15.750	22.000	R	1,330	3,200.3	
	30.875	2.250	S	622	300.1	
	24.375	2.250	S	3,052	1,162.4	
	16.500	2.250	S	4,422	1,140.1	
	13.875	2.250	S	1,119	242.7	
			NO. 1 COMMON[b]			
3,798	73.375	2.250	S	346	396.7	87.4
	62.500	2.875	S	294	366.6	
	56.875	2.250	S	225	200.0	
	37.875	2.875	S	685	518.1	
	24.375	2.250	S	1,412	537.7	
	16.500	2.250	S	759	195.7	
	13.875	2.250	S	242	52.4	
			FIRSTS AND SECONDS[b]			
656	62.500	2.875	S	266	332.1	8.5
	37.875	2.875	S	109	82.3	
	16.500	2.250	S	249	64.1	
	13.875	2.250	S	23	4.9	
19,664				15,383	9,892.5	613.0

[a]R = random; S = specified.
[b]4/4 lumber thickness.

It provides the input volume for each grade according to the least-cost mix, the cutting sizes that are to be obtained from each grade, and the number of pieces that are expected from that volume of lumber.

The computer evaluates all combinations of cutting requirements and yield per grade to determine the least-cost combination. The results are not always according to tradition. For example, in the cutting instructions shown (Table 2), the longest length in the cutting order (73.375 inches) is obtained exclusively from 1C and not FAS. Instead, FAS is used to supplement the requirements for the 62.5, 37.875, 16.5, and 13.875 cutting lengths. However, this combination of lengths results in a 73.7-percent yield of cuttings from FAS (Table 1).

The cutting instructions also include the value "board feet shorts." This represents the net board feet of unused volume that would be available as 10-inch-long, random-width cuttings. As such, it provides an indication of how well the raw material is being utilized.

In addition to information on each grade, there is a summary for the entire cutting order. Included are the total gross volume of lumber required, the total net board feet of cuttings to be obtained, the total board feet of shorts anticipated, and the total number of pieces required.

WALNUT as a Decisionmaking Tool

Because walnut lumber is an expensive commodity, relatively small adjustments in the grade composition of the lumber going to the rough mill can have significant effects on the cost of the dimension produced.

WALNUT can be a valuable tool in determining the best, or least-cost, combination of grades to use for specific cutting orders. If an adequate quantity of a specific grade recommended in the least-cost mix is not available, WALNUT can be rerun using the volume constraints feature to determine the next best alternative.

The upper and lower input cost levels shown in the range and sensitivity analysis are an indication of the relative value of each grade in relation to the value of the other grades when used in a particular cutting order. Consequently, decisions regarding the allocation of lumber to several cutting orders can be made.

For instance, assume that in scheduling the daily cutting orders to be processed by the rough mill, there was not enough 1C available to satisfy the least-cost grade mix for two separate cutting orders. By comparing the upper input cost level for 1C lumber in each cutting order, the manager could elect to allocate the available 1C to the cutting order with the highest upper limit because that is where 1C would have its highest value use. The remaining 1C would be used in the other cutting order, which would be reevaluated using the volume constraints feature in WALNUT. By allocating the available 1C lumber in this manner, the total cost of processing the pair of cutting orders would be at a minimum. More than two orders would be handled in the same way, always giving priority to the cutting order providing the highest valued use of a particular grade.

WALNUT, and its companion programs OPTIGRAMI and YELLOPOP ("Producing Yellow-Poplar Furniture Dimension at Minimum Cost Using YELLOPOP," USDA Forest Service Research Paper NE–592, in press), can provide valuable insight into numerous other management decisions besides specific least-cost grade mixes. OPTIGRAMI is used to evaluate cutting orders from all species graded by the standard National Hardwood Lumber Association rules and YELLOPOP is used for yellow-poplar. As management tools, they can help in making decisions regarding the grades of lumber that should be purchased, scheduling of lumber to be dried, improving rough-mill efficiency, or improving yields through changes in design. Creative managers will find additional applications.

Using WALNUT

WALNUT is designed for use on any IBM mainframe computer with a mathematical programing system (MPS) in its program library. The program can be accessed through an on-site computer or through a remote terminal.

Remote Terminal

For users wishing to use a remote terminal, WALNUT has been placed on the Computerized Management Network (CMN)—a national time-sharing computer service managed by the Virginia Cooperative Extension Service. Access to CMN can be made with any ASCII terminal and a modem, or with a microcomputer with a communications program.

CMN is accessed through normal long distance telephone lines. To LOG ON, you will need to obtain a CMN user identification number (userid) and password by contacting:

> Virginia Polytechnic Institute & State University
> Virginia Cooperative Extension Service
> Extension Computing Resources
> Plaza I, Building D
> Blacksburg, VA 24061
> 703-961-5184

There is no initial fee or hookup charge for CMN, but there is a small monthly userid ownership charge.

To use the program, simply dial the computer telephone number and LOG ON with your CMN userid and password. The computer will then ask you what program you would like. Enter "WALNUT." The Main Menu (Fig. 4) will ask what you would like to do. By pressing one of the four function (PF) keys, you can request a file for editing or analysis, determine if a submitted analysis has been returned to your userid, get the HELP file, or exit the program. If you wish to make a WALNUT analysis, press the PF4 key. A File Specification screen will ask you to enter a file name (Fig. 5). The file names that you have previously run also will be listed. To enter a file name, enter a name of from one to eight characters in the file name field and press the ENTER key, or position the cursor at the name of one of your existing files and press ENTER (this copies the name at the cursor to the file name field at the top of the screen); press ENTER again to validate the name you have selected. A message will appear at the bottom of the screen indicating that the requested file is an old file.

Now that you have selected your file, press the PF8 key to proceed to the File Options screen (Fig. 6). Press a PF key to select whether you want to edit the select file (PF4), submit the file for processing (PF5), or specify your job priority (PF6). Since we are interested in making an analysis, we would press PF4 to proceed to the Data Entry screen (Fig. 1). You can move the cursor with the cursor controls or skip from field to field with the TAB key.

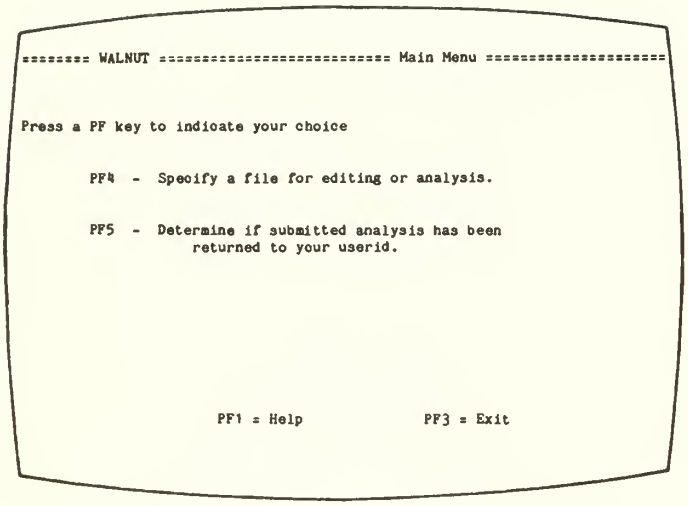

======== WALNUT ========== Main Menu ==========
Press a PF key to indicate your choice
PF4 - Specify a file for editing or analysis.
PF5 - Determine if submitted analysis has been returned to your userid.
PF1 = Help
PF3 = Exit

Figure 4.—Main Menu screen.

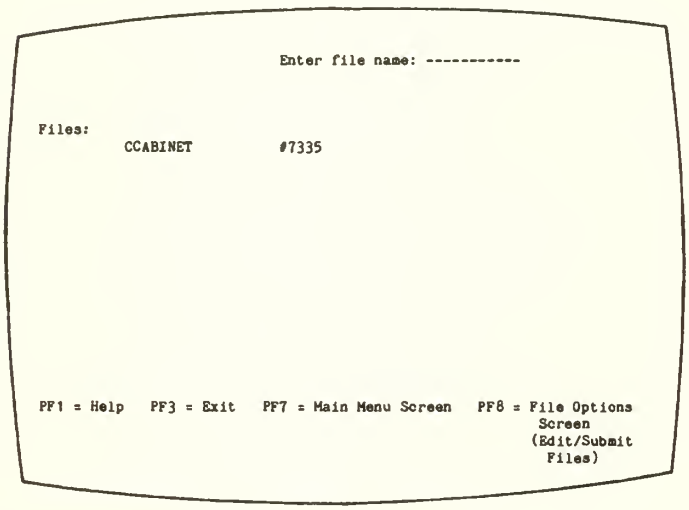


Figure 5.—File Specification screen.

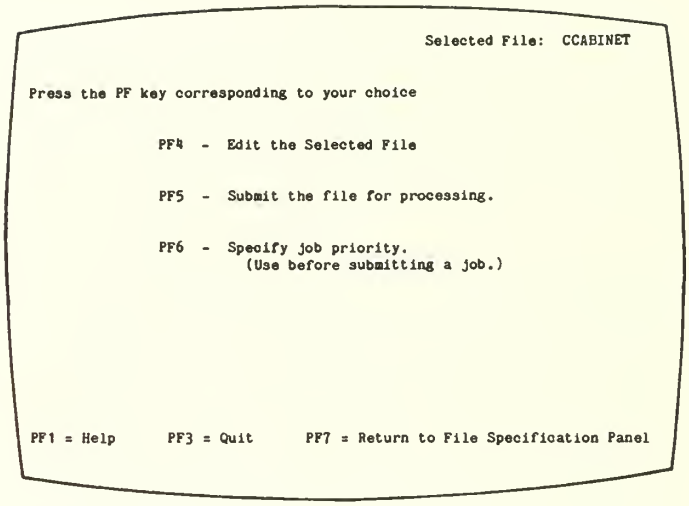

Selected File: CCABINET
Press the PF key corresponding to your choice
PF4 - Edit the Selected File
PF5 - Submit the file for processing.
PF6 - Specify job priority. (Use before submitting a job.)
PF1 = Help PF3 = Quit PF7 = Return to File Specification Panel

Figure 6.—File Options screen.

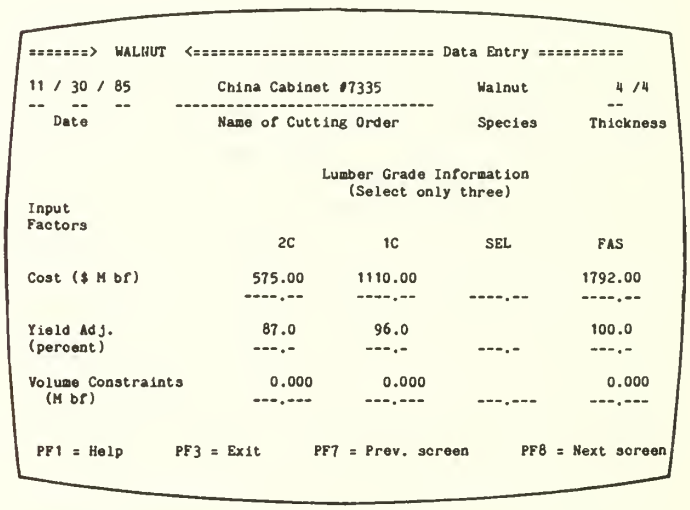
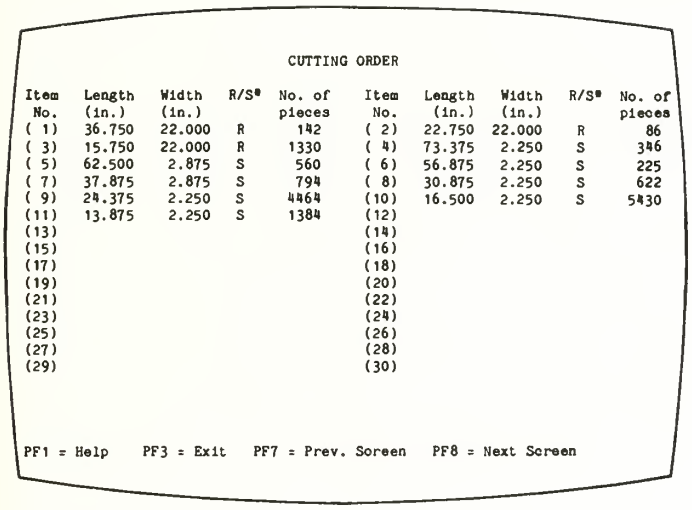

=======> WALNUT <========== Data Entry ==========
11 / 30 / 85 China Cabinet #7335 Walnut 4 /4
Date Name of Cutting Order Species Thickness
Lumber Grade Information (Select only three)
Input Factors
2C 1C SEL FAS
Cost ($ M bf) 575.00 1110.00 1792.00
Yield Adj. (percent) 87.0 96.0 100.0
Volume Constraints (M bf) 0.000 0.000 0.000
PF1 = Help PF3 = Exit PF7 = Prev. screen PF8 = Next screen

Figure 7.—Completed Data Entry screen.

On the completed Data Entry screen (Fig. 7), we have specified 4/4 thickness and the lumber grades of 2C, 1C, and FAS. The input costs of $575, $1,110, and $1,792 reflect estimates of the total of costs for each grade through the rough mill. The 87– and 96–percent yield adjustments for 2C and 1C are for demonstration purposes only. Since no volume constraints were used, the program assumes that there are unlimited volumes available for each grade. We would now press PF8 to move to the Cutting Order screens (Figs. 8–9). Part sizes do not need to be entered in a particular order, such as from longest to shortest.

Pressing the PF8 key takes us to screen 2 of the cutting order (Fig. 3) and pressing PF8 again takes us to the File Options screen (Fig. 6). By pressing PF6, we can specify our job priority (Fig. 9). Five levels of priority can be selected, from idle (least expensive) to urgent (most expensive). If no selection is made, the program is set to run on idle priority. Assuming that we are satisfied with our priority, we press PF5 to submit our file for processing. We will receive a message at the bottom indicating "WALNUT job submitted. Check for results after 10 minutes."

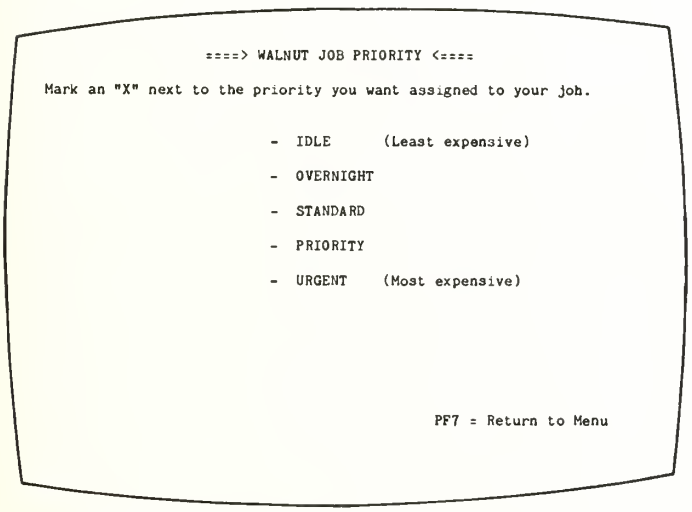


CUTTING ORDER

Item No.	Length (in.)	Width (in.)	R/S*	No. of pieces	Item No.	Length (in.)	Width (in.)	R/S*	No. of pieces
(1)	36.750	22.000	R	142	(2)	22.750	22.000	R	86
(3)	15.750	22.000	R	1330	(4)	73.375	2.250	S	346
(5)	62.500	2.875	S	560	(6)	56.875	2.250	S	225
(7)	37.875	2.875	S	794	(8)	30.875	2.250	S	622
(9)	24.375	2.250	S	4464	(10)	16.500	2.250	S	5430
(11)	13.875	2.250	S	1384	(12)				
(13)					(14)				
(15)					(16)				
(17)					(18)				
(19)					(20)				
(21)					(22)				
(23)					(24)				
(25)					(26)				
(27)					(28)				
(29)					(30)				

PF1 = Help PF3 = Exit PF7 = Prev. Soreen PF8 = Next Screen

Figure 8.—Completed cutting order (screen 1).



====> WALNUT JOB PRIORITY <====

Mark an "X" next to the priority you want assigned to your job.

- IDLE (Least expensive)
- OVERNIGHT
- STANDARD
- PRIORITY
- URGENT (Most expensive)

PF7 = Return to Menu

Figure 9.—WALNUT job priority.

We can now press PF4 to make changes in our file if we want to rerun it with different lumber input costs, yield adjustments, or volume constraints. If we want to enter another analysis, we press PF7 to return to the File Specification screen (Fig. 5).

To receive our WALNUT output, we return to the Main Menu (Fig. 4) and press the PF5 key to determine if our submitted analysis has been returned to our userid. If it has not, we will receive a message at the bottom of the screen saying "No WALNUT output has been returned. Try again later." When the analysis is completed, the output is returned to your "reader." To look at the output, press PF11. This makes the entire WALNUT output available to you. You can scroll forward or backward by using the PF8 and PF7 keys.

If you wish to keep the output, press the PF9 key to have it recorded onto your CMN disk space as a permanent record or to have it printed. If you have a printer attached to your terminal, you can have the results printed by using the command "TPRINT" followed by the file name that you used (Fig. 5). You can discard the output by pressing the PF2 key or have it printed at Virginia Polytechnic Institute and State University (VPI&SU) by pressing the PF4 key. VPI&SU will then send you the results. Pressing the PF3 key returns you to the Main Menu.

On every screen requiring the selection of an option or the input of data, the PF1 key has been labeled HELP. By pressing it, a help file will be displayed to explain each of the options available to you.

Mainframe

Users who have access to an IBM mainframe computer can obtain a free copy of our WALNUT program library by sending a blank tape to the Forestry Sciences Laboratory, P.O. Box 152, Princeton, West Virginia 24740. The library will be copied onto it and returned with documentation.

If the IBM mainframe does not have an MPS in its program library, it will be necessary to obtain it before WALNUT will function. An MPSX can be obtained from an IBM representative or an MPSIII can be obtained from KETRON, Inc., Management Science System Divisions, 1400 Wilson Boulevard, Arlington, Virginia 22209.

All features available on the CMN version also are available on the mainframe version and they are operated identically.

Summary

WALNUT can make a signifcant difference in the total cost of walnut dimension parts by selecting the most economical combination of grades and volumes required to produce a given cutting order. WALNUT and its companion programs, OPTIGRAMI and YELLOPOP, are decisionmaking tools designed to help furniture and dimension rough-mill managers. They are easy to use and are adaptable to individual plant situations.

The computer program described in this publication is available on request with the understanding that the

U.S. Department of Agriculture cannot assure its accuracy, completeness, reliability, or suitablity for any other purpose than that reported. The recipient may not assert any proprietary rights thereto nor represent it to anyone as other than a Government-produced computer program.

Appendix

Table 3.—Predicted yields of random-width cuttings from FAS grade walnut lumber (net board feet per M bf)

Length of subsequent cuttings (inches)	Length of longest cuttings									
	10	20	30	40	50	60	70	80	90	96
	Inches									
96										180
90									280	312
80								360	398	422
70							432	482	510	534
60						478	530	572	592	608
50					498	544	582	618	638	648
40				560	600	612	628	652	672	680
30			620	660	678	680	682	684	690	706
20		670	702	724	730	730	730	730	730	732
10	730	750	760	762	762	760	760	758	758	750

Table 4.—Reduction values for obtaining predicted yields for cuttings of specified widths from FAS grade walnut lumber (net board feet per M bf)

Width of cuttings (inches)	Length of cuttings									
	10	20	30	40	50	60	70	80	90	96
	Inches									
2	40	36	30	28	22	20	16	10	8	4
3	70	64	56	48	40	36	30	22	18	10
4	112	96	86	78	68	60	46	30	20	14
5	266	246	230	220	208	198	188	168	138	84
5-½	380	354	336	320	302	285	264	226	180	118

Table 5.—Predicted yields of random-width cuttings from SEL grade walnut lumber (net board feet per M bf)

Length of subsequent cuttings (inches)	Length of longest cuttings								
	10	20	30	40	50	60	70	80	90
	Inches								
90									144
80								194	226
70							256	306	336
60						316	380	414	432
50					380	436	468	490	504
40				442	502	526	542	556	562
30			518	574	590	602	608	610	612
20		596	638	652	660	662	660	662	664
10	672	690	702	708	708	706	704	702	702

Table 6.—Reduction values for obtaining predicted yields for cuttings of specified widths from SEL grade walnut lumber (net board feet per M bf)

Width of cuttings (inches)	Length of cuttings								
	10	20	30	40	50	60	70	80	90
	Inches								
2	46	38	32	26	20	16	10	6	3
3	100	80	70	60	48	40	32	26	18
4	202	178	160	140	130	120	104	80	56
5	380	356	326	296	264	230	192	152	106
5-½	470	436	398	362	324	284	238	186	126

Table 7.—Predicted yields of random-width cuttings from No. 1 Common walnut lumber (net board feet per M bf)

Length of subsequent cuttings (inches)	Length of longest cuttings							
	10	20	30	40	50	60	70	80
	Inches							
80								86
70							140	170
60						198	238	256
50					270	310	338	352
40				344	400	422	434	440
30			440	488	508	522	526	530
20		530	570	586	594	598	600	600
10	626	644	652	656	654	652	650	650

Table 8.—Reduction values for obtaining predicted yields for cuttings of specified widths from No. 1 Common walnut lumber (net board feet per M bf)

Width of cuttings (inches)	Length of cuttings							
	10	20	30	40	50	60	70	80
	Inches							
2	38	28	20	16	10	8	5	2
3	106	96	84	66	46	38	32	28
4	256	228	198	172	154	128	98	66
5	420	382	338	280	234	186	138	80
5-½	470	436	378	318	260	201	146	84

Table 9.—Predicted yields of random-width cuttings from No. 2 Common walnut lumber (net board feet per M bf)

Length of subsequent cuttings (inches)	Length of longest cuttings						
	10	20	30	40	50	60	70
	Inches						
70							50
60						80	100
50					138	162	174
40				220	254	270	276
30			308	358	378	386	386
20		428	464	476	480	482	482
10	528	546	556	556	550	546	546

Table 10.—Reduction values for obtaining predicted yields for cuttings of specified widths from No. 2 Common walnut lumber (net board feet per M bf)

Width of cuttings (inches)	Length of cuttings						
	10	20	30	40	50	60	70
	Inches						
2	58	40	30	26	18	14	10
3	170	146	118	92	70	50	30
4	300	268	218	170	118	78	40
5	406	358	292	218	132	84	46
5-½	448	398	318	228	141	88	50

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Martens, David G. **Reduce dimension costs by using WALNUT**. Res. Pap, NE-586. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1986. 10 p.

A computer program called WALNUT is described that determines the least-cost combination of lumber grades required to produce a given cutting order of furniture dimension parts. If the least-cost mix is not available, WALNUT can be used to determine the next best alternative. The steps involved in using the program are described.

ODC 836.1

Keywords: furniture, hardwood dimension; lumber yields; dimension yields

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The Economic Importance of Vermont's Sawtimber

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Abstract

This paper concentrates on the potential economic importance of Vermont's sawtimber. The timber industry employed over 9,000 workers in 1980, and the value of stumpage cut that year was worth approximately $459 million to the State's economy. Preliminary resurvey data indicate that sawtimber inventory now exceeds 14 billion board feet. Yet, sawtimber removals have averaged only 200 million board feet per year over the last 10 years. We used an input-output model called IMPLAN V1.1 to predict socio-economic impacts of several sawtimber production levels. The results indicate that improved markets for the existing resource could significantly contribute to the State's economy. If 50 percent of the projected annual growth could be marketed, an additional $152 million contribution could be made to the State's gross product and over 9,000 new jobs created.

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Introduction

The importance of forest resources in the State's economic base has long been recognized (Bonyai and Sendak 1982, Healy 1984, Kingsley 1977). Quantitatively estimating forest resource values, however, continues to be a challenge. Three recent and related projects that were analyzed for issues related to the economic importance of the State's forest resources were: (1) The Fourth Comprehensive Forest Inventory of the State (1983); (2) A Study of Alternative Futures for Vermont (1982); and (3) A State Forest Resources Planning Project (1980-85).

Forest surveys by the USDA Forest Service have been conducted in 1948, 1966, 1973, and 1983. From findings of the 1983 resurvey, the following information is pertinent to the wood fiber supply (Frieswyk and Malley 1985):

- Seventy-five percent of the State's land area is classified as timberland.
- Northern hardwoods type group make up 61 percent of all timberland.
- Volume of growing stock increased by 25 percent since the last survey (1973) with sawtimber volumes rising by 22 percent.
- The area of the sawtimber stand-size class increased by 45 percent since the last inventory.
- Sawtimber volumes on timberland averaged 3,163 board feet per acre; an increase of 22 percent since the last inventory.
- Sawtimber inventory increased to 14 billion board feet compared to less than 11.5 billion in 1973.
- However, annual sawtimber removals continued to average about 200 million board feet since 1973.

In January 1984, representatives of the forestry community were asked by the State Forester to set priorities on how the resurvey data should be analyzed. An analysis of the economic importance of forestry and forest-related industries was the top concern of the respondents.

The Vermont Futures Project of June 1982 also involved a cross-section of the State's forestry community.[1] These representatives assessed the current resource situation and proposed future goals (2030) for various forest resources. Some of the wood fiber goals are depicted in Table 1.

These goals, reached by concensus among resource experts, are based on biological supply relationships. The experts assumed that demand for the increased product flow from the forest will materialize through increased demand for the goods that require Vermont wood in their manufacture. Will such an increase in demand come about? The answer partly resides in the market place; it is beyond the scope of this analysis.

Table 1.—Wood fiber goals proposed by the Vermont Futures Project

Item	As of 1980	Desired for 2030
	Percent	*Percent*
Volume of annual growth harvested		
Cut and removed	16	47
Cut and left	24	6
Uncut	60	47
Cut as percentage of current annual growth, by owner class		
State/municipal	73	Slight increase
Federal	79	Slight increase
Industry	90	Same
Other private	25	Major increase
Wood uses		
Pulp	21	Decrease
Fuelwood	43	Major increase
Sawtimber	35	Increase

Source: Institute for Alternative Futures. Alternative futures for Vermont—a strategic workbook for forests, parks, and recreation. Montpelier, VT: Vermont Agency of Environmental Conservation, Division of Planning and Department of Forests, Parks, and Recreation; in cooperation with: Rutland, VT: U.S. Department of Agriculture, Forest Service, Green Mountain National Forest. Alexandria, VA: Institute for Alternative Futures; 1982. 114 p.

The latest effort in state forest resources planning began around 1980. A draft State Forest Resources Plan was out for public review in mid-1985. Extensive public participation identified major forest resource issues. The following strategies were recommended (O'Dell 1982) for Issue A, "Opportunities for timber, fuel, and fiber production."

- Explore new markets for high-quality, short pieces of hardwood lumber.

[1]Institute for Alternative Futures. Alternative futures for Vermont—a strategic workbook for forests, parks, and recreation. Montpelier, VT: Vermont Agency of Environmental Conservation, Division of Planning and Department of Forests, Parks and Recreation; in cooperation with: Rutland, VT: U.S. Department of Agriculture, Forest Service, Green Mountain National Forest. Alexandria, VA: Institute for Alternative Futures; 1982. 114 p.

- Promote products produced by Vermont's wood-using industry.
- Explore potential export markets and inform local manufacturers of possibilities.
- Encourage management for high-quality sawlogs.
- Initiate special programs to increase management for the regeneration, growth, and supply of white pine.
- Publish forest product market information.
- Support a timber commodities market.

Finally, a joint federal-state program review for forestry planning recommended that the socio-economic importance of selected forest resources should be determined using resurvey data trends, published economic reports, and final plan direction.[2]

Scope and Objectives

Our analysis focuses on sawtimber production for a variety of reasons. Vermont has a significant sawmill industry that is supplied largely from its own forest resource. Although much pulpwood is cut in the State, most notably in the northeastern counties, almost all of it is exported to other states. Therefore, the value added from pulpwood is considerably less than that from sawlogs. Other forest values—water, recreation, wildlife, esthetics—are not addressed in this analysis, though they clearly have a significant impact on Vermont's economy (Kingsley 1977).

Although the use of low-quality wood for fuel both as solid wood—primarily for home heating—and wood chips—primarily for electrical generation and cogeneration and for process steam—is on the rise, the model we used for the analysis was incapable of incorporating this relatively new demand. Similarly, reconstituted wood products such as waferboard and oriented strand board are likely to create new markets in the future for low-quality wood in Vermont. The model was incapable of anticipating when this demand would occur or how it will affect the economy.

The specific objectives of our analysis were to: (1) determine the potential economic impacts and relative importance of sawtimber to Vermont's economy, and (2) measure potential impacts to the year 1995 under various sawtimber production alternatives.

[2]Michaels, Joseph A.; Motyka, Conrad M. Vermont cooperative program review—planning assistance program. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry; 1984. 13 p. Unpublished report.

Overview of Vermont's Timber Economy

Current Economic Significance

According to Bonyai and Sendak (1982), timber industry employed more than 9,000 workers in 1980 and paid about $110 million in gross wages. This employment figure represented nearly 5 percent of all workers in the State and 18 percent of all those employed in manufacturing. The estimated value of stumpage cut that year was $9.2 million which in turn was worth approximately $459 million to the State's economy after secondary and tertiary impacts. The lumber and wood products industry had 333 establishments. Sawmills consumed about 211 million board feet of timber in 1980. The state is a net exporter of softwood sawlogs and a net importer of sawlogs overall. Overseas exports accounted for only 3 percent of all wood product shipments. Healy (1984) says that between 1970-80:

- The largest increase of employed persons in forest product related occupations was in timber cutting and logging—744 more people than in 1970 or a 140 percent increase.
- Nationally, forest product related occupations grew by only 9 percent compared to Vermont's 66 percent growth. For every person directly engaged in a forest product related job activity, there were 1.3 additional workers doing nondirect forest related work.
- Employment in forest product related industries expanded by 33 percent.

Sawtimber Resource Trends

Since World War II sawtimber removals hit a high of 273 million board feet in 1951 and a low of 127 million in 1971. Hardwood-softwood mix by volume is 65-35 percent. About 90 percent of the commercial forest land is currently in private ownership. Average removal over the last 10 years (1974-83) was 198 million board feet (Gove 1983). Resurvey data (Frieswyk and Malley 1985) indicate that sawtimber inventory has risen from 6.5 billion board feet in 1966 to nearly 14 billion in 1983—a 115 percent increase. Average annual net growth, gross growth minus mortality and cull increment, for sawtimber was only 175 million board feet in 1966; rose to 262 million by 1972, and was approaching 500 million board feet in 1983. Average annual net growth exceeds removals by more than 100 percent. Figure 1 shows the relationship between inventory, growth, and removals. Projection estimates are based on extrapolated resurvey data.

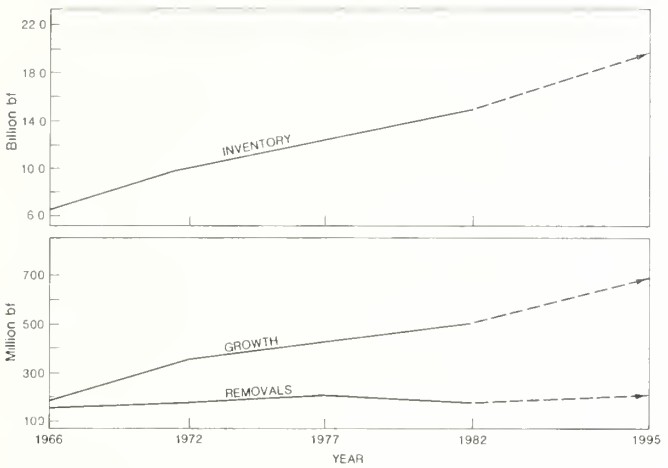

Figure 1.—Sawtimber inventory, average annual net growth (Frieswyk and Malley 1985), and removals (Gove 1983), 1966–95.

Marketing Opportunities and Constraints

Despite the rising inventory and widening gap between growth and removals, Vermont remains a net importer of sawlogs. Part of this imbalance is due to mills located on or near the State border that get their supply from neighboring states such as New York, Massachusetts, and New Hampshire. Only 3 percent of the 200 million board feet currently being harvested is reaching foreign export markets (Bonyai and Sendak 1982). One of the reasons for this small export ratio is the relatively poor quality of the sawtimber. Grade 1 logs accounted for only 1 percent of the pine and 9 percent of the hardwood sawtimber in 1972. 1983 data indicate an increase to 5 percent for pine and 11 percent for hardwood. As the sawtimber in the smaller size classes grows into larger size classes, the percentage of grade 1 sawlogs will increase, improving marketability.

Several other probable factors constrain sawtimber harvest including lack of owner awareness on nonindustrial private holdings, increasing numbers of absentee owners, and constrained timber sale preparation budgets on some public lands.

Estimating Economic Potentials

I-O Models—IMPLAN V1.1

Input-output (I-O) models have traditionally been used to characterize a developed economy. Vermont's economy can be described through an analysis of the interdependence among producing sectors. Each sector not only produces goods or services but also is a consumer, purchasing other goods and services for use in its production process. These relationships among industry inputs and outputs were developed into a general theory of production by Wassily Leontief in the 1930's. Leontief's original Input-Output Table of the United States showed how each sector of the economy depended on every other sector (Leontief 1951).

Input-Output tables for the U.S. economy are periodically prepared by the Bureau of Economic Analysis, U.S. Department of Commerce, using data directly obtained from reporting industries. The Bureau does not prepare regional or state Input-Output tables. Regional or state models are generally constructed either by directly surveying all the industries in the study area ("survey-based") or by methods that modify the national model ("nonsurvey-based"). Survey-based models are generally viewed as superior to nonsurvey tables because they are more accurate for the region of interest. But, they are also more expensive and require substantial lead time to develop the survey, conduct it, and then compile the table. By contrast, nonsurvey models rely on a variety of economic statistics gathered by public agencies and private firms. Individual regional or state models are then estimated using average inter-industry production relationships, regional activity levels, and regional trade balances that define the trade relationships between the region and the rest of the world.

Several assumptions are inherent in an I-O model analysis (Convery 1977). Some of the major ones are:

- Inputs are used by industries in fixed proportions.
- All inputs are assumed to be available as expansion in production occurs.
- The accounting period is 1 year.
- Each industry has a single product output.

The I-O model is therefore classified as a static model. That is, it paints a picture of the economy at the instant in time for which the data were collected. However, I-O is used as a planning tool to study, for example, impacts on the economy caused by changing production over time from an industry—in essence, studying a dynamic process with a static model. This can be a problem as new industries emerge, old ones fail, and technology generally advances changing factor proportions.

This problem is evident in this analysis. The "new" industry of fuelwood production is not represented in the model so we cannot study its impact on the economy. Similarly, we anticipate that reconstituted board products will emerge as an important wood-using industry in Vermont in the near future. It too is not in the model and future impacts cannot be analyzed.

Nevertheless, the sawtimber-using industries are a part of the model. We do not anticipate that they will decrease in

significance over the future we are analyzing (to 1995). And, we expect that the factor proportions will remain roughly fixed for these industries over the period of analysis.

IMPLAN V1.1 is an I-O Model with predictive capabilities (Alward and Palmer 1983). It was selected as the primary economic tool for the sawtimber analysis.

IMPLAN V1.1 data base consists of two major parts: (1) a national-level technology matrix that indicates the proportion of inputs needed to produce outputs, and (2) estimates of sectoral activity for final demand, final payments, gross outputs, and employment for each county in the nation. The 466 Sector National Technology Matrix, which is used to estimate local purchases and sales, was derived from the Department of Commerce's 1972 national input-output table updated to 1977. The USDA Forest Service has announced that a revised software system will be available in late 1985 (IMPLAN V2.0), and the fully revised system with data base updated to 1982 will be operational in early 1986 (USDA Forest Service 1984).

Despite the built-in limitations inherent in any I-O Model and the 1977 data base for the IMPLAN V1.1 System, IMPLAN V1.1 was selected as the analysis tool because for many purposes it predicts reasonably well, and it is inexpensive to use.

These components of IMPLAN V1.1 were used in the Vermont Sawtimber Analysis:

REGION—Enables the user to develop a set of border totals (final demand, final payments, total gross outputs, and employment) for the impact area being studied. In this analysis, it was the 14-county area of Vermont.

SCALE—Utilizes the national technical coefficients and the regional border totals to estimate a set of regional purchase coefficients. Prepares a balanced set of regional accounts including competitive and non-competitive imports, as well as domestic exports.

SMASH—Enables the user to aggregate the 466 industry sectors to concentrate the analysis on the sectors of special interest. In this analysis, three sectors were important to sawtimber production: Sawmills and planing mills, veneer and plywood, and household furniture.

INVERT—Converts the regional set of accounts constructed using SCALE or SMASH to a predictive model by calculating the Leontief inverse for the open (without households endogenous) and closed (with households endogenous) models.

IMPACT—Enables analyst to manipulate economic vectors for final demand, and total gross output to calculate economic impacts for employment, income and changes in population.

Sawtimber Alternatives

Sawtimber alternatives were based on the following question: If markets were expanded to accommodate increased sawtimber production, what would be the economic impacts on Vermont's economy?

Data used and assumptions made include:

1. Timber mix was 70 percent hardwood and 30 percent softwood.

2. Unit of production used was millions of board feet (MMbf).

3. Timber production was assumed to impact mainly three sectors: SIC (Standard Industrial Classification) 137 Sawmills and Planing Mills; SIC 142 Veneer and Plywood; SIC 150 Household Furniture. Further analysis down the chain of production was not realistic, since the sources of supply could not be distinguished.

4. The timber share assigned to these sectors was 50 percent SIC 137, 10 percent SIC 142, and 40 percent SIC 150.

5. Value per unit in 1977 dollars of finished product assigned to each sector was: $175 per Mbf for sawmills and planing mills, $545 per Mbf for veneer and plywood, and $1,000 per Mbf for household furniture.

6. All production changes were assumed to take place by the end of 1995.

Four sawtimber production change alternatives were analyzed:

Alternative 1—Impact of 175 MMbf production level based on the 1982 output (current or base).

Alternative 2—Impact of a 20 percent increase in production based on improved markets. Production would increase to 210 MMbf per year.

Alternative 3—Impact of a 20 percent decrease in production. Production would drop to 140 MMbf per year.

Alternative 4—Impact of being able to market 50 percent of the projected growth to 1995. Projected net annual growth (see figure 1) is estimated to be 775 MMbf. The new production level target would be 388 MMbf per year.

See Table 2 for the alternative data used in the IMPLAN run.

Table 2.—Alternative data for IMPLAN V1.1

Alternative	Sector impacted	Cost per Mbf	Production level assigned
		Dollars	*MMbf*
1	137	175	88
(175)	142	545	18
MMbf	150	1,000	69
2	137	175	105
(210)	142	545	21
MMbf	150	1,000	84
3	137	175	70
(140)	142	545	14
MMbf	150	1,000	56
4	137	175	194
(388)	142	545	39
MMbf	150	1,000	155

Projected Economic Impacts

Table 3 summarizes potential economic impacts resulting from IMPLAN V1.1 runs. Table 3 is not a replication of the IMPLAN V1.1 output, but rather an interpretation of the results. For instance, the IMPLAN V1.1 impact report projects changes in value added. The sum of value added is used as an approximation of gross state product (GSP)—the total value of all goods and services produced in a year. Copies of the total change impact reports can be found in the Appendix.

These data represent estimates based on 1977 transaction coefficients. The relative differences between alternatives probably have more validity than the actual numbers. IMPLAN V1.1 impacts are categorized as direct (affecting only the sectors with the production change), indirect (impacts on support industries such as services and retail trade), and induced (an effect on the household sector as a consequence of the increased production from the direct and indirect effects). Data in Table 3 represent total impact or the sum of direct, indirect, and induced. Finally, "jobs" are comprised of a mix of full-time and part-time employment.

Findings and Conclusions

Although Vermont has an inventory of 14 billion board feet of sawtimber, only a small fraction of it is being marketed. Removals have averaged only 200 MMbf per year over the last 10 years—less than half of the average net annual growth. Quality is a problem but is improving as small sawtimber grows into the larger size classes.

Vermont Future's work has encouraged the forestry community to:

Table 3—Alternative impacts

Alternatives	Contribution to GSP[a]	Net increase or decrease from base	Number of jobs	Net increase or decrease in number of jobs from base	GSP percent of total economy	Percent change of GSP from base	Jobs, percent of total economy	Jobs, percent change from base	Additional people affected[b]
	Millions of dollars					—	(1.6)	—	—
Base year	(45)[c]	—	(3,494)	—	(2.0)	—	[3.3]	—	—
(1977)	[123][d]	—	[7,429]	—					
(175 MMbf)					[5.4]				
						(+0.4)	(1.9)	(+0.3)	(1,621)
+ 20 percent	(54)	(+ 9)	(4,231]	(+ 737)	(2.4)	[+1.1]	[4.0]	[+0.7]	[3,434]
(210)	[149]	[+ 26]	[8,990]	[+ 1,561]	[6.5]				
						(−0.4)	(1.3)	(−0.3)	(1,481)
− 20 percent	(36)	(− 9)	(2,821)	(− 673)	(1.6)	[−1.1]			[3,159]
(140)	[99]	[− 24]	[5,993]	[− 1,436]	[4.3]		[2.7]	[−0.6]	
50 percent									
potential	(99)	(+ 54)	(7,812)	(+ 4,318)	(4.3)	(+2.3)	(3.5)	(+1.9)	(9,500)
(388)	[275]	[+152]	[16,600]	[+ 9,171]	[12.0]	[+6.6]	[7.5]	[+4.2]	[20,176]
Total economy 1977	2,289		222,087						

[a]Gross state product—value of all goods and services produced in one year.
[b]Based on an average of 2.2 people supported by each new job. (Population to jobs ratio.)
[c]Numbers in parentheses represent data for sectors 137, 142, and 150 only
[d]Numbers in brackets represent data for all 466 sectors

- Increase the volume of annual growth harvested significantly (from current 16 percent to 47 percent).
- Increase harvesting on nonindustrial private land.
- Increase fuelwood and sawtimber production at the expense of pulpwood.

The statewide forest resource plan will place much emphasis on strategies for marketing development and increasing exports.

The existing timber resource as assessed from the recent resurvey, the desired future for that resource, and planned strategies for realizing that future give Vermont the potential to realize some important economic development from its sawtimber supply. Highlights from the IMPLAN analysis indicate that:

- For every additional 1 MMbf of sawtimber marketed, another 42 jobs can be supported . . . 17 within the three sectors directly affected and another 25 jobs in sectors incurring indirect and induced changes.
- The supporting sectors that would benefit most from increased sawtimber production are: retail trade (SIC 433), wholesale trade (SIC 432), and professional and personal services (SIC 440).
- A marketing effort that could increase sawtimber production by 20 percent would mean an additional $26 million to the State's economy. Over 700 new jobs would be created in the sawlog portion of the State's timber industry and a total of 1,561 jobs throughout Vermont's economy. Sawtimber's contribution to the gross state product would exceed 6.5 percent. Nearly 3,500 people would be supported by these new employment opportunities based on the current population to job ratio.
- Approximately 9 new mills would be needed to process the additional sawtimber output.
- Failure to improve markets and/or increase out-of-state shipments could mean the loss of $24 million and 1,400 jobs. More than 3,000 people could be adversely impacted.
- On the other hand, if a vigorous marketing effort was able to capture 50 percent of the projected (1995) annual growth, some very significant socio-economic impacts could be realized:

  —$152 million increased contribution to Vermont's gross state product.

  —More than 9,000 new jobs.

  —More than 20,000 people supported by new employment opportunities.

  —More than 50 new mills would be needed to process the additional sawtimber output.

Vermont has an opportunity to help create its desired future for sawtimber production through successful implementation of its statewide plan—and make some significant contributions to its economic base.

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Appendix

Definition of Terms

Average annual net growth. The change, resulting from natural causes, in growing-stock or sawtimber volume of sound wood in growing-stock or sawtimber trees during the period between surveys, divided by the length of the period. Components of average annual net growth include the increment in net volume of trees that are present at the beginning of the period and that survive to the end (accretion), plus average annual ingrowth, minus average annual mortality, and minus the net volume of trees that became rough or rotten during the period (cull increment).

Average annual removals. The net growing-stock or sawtimber volume of trees harvested or killed in logging, cultural operations—such as timber stand improvement—or land clearing, and also the net growing-stock or sawtimber volume of trees neither harvested nor killed but growing on land that was reclassified from commercial forest land to noncommercial forest land during the period between surveys. This volume is divided by the length of the period.

Board foot. A unit of lumber measurement 1 foot long, 1 foot wide, and 1 inch thick, or its equivalent.

Domestic final demand. The sum of all purchases for consumption by consumers both inside and purchases for consumption and use in production by consumers and industries outside the region but inside the United States. Domestic final demand includes the sum of personal consumption expenditures, capital formation, inventory change, state and local government expenditures, federal government expenditures, and domestic exports.

Employee compensation. Wages and salaries (including benefits) paid to employees by the firms within each sector.

Grade 1 log. A tree generally 14 inches or larger in diameter at breast height, at least 10 feet in length without trim, and having a minimum of 5/6 clear cutting on each of the three best faces.

Gross state product (GSP) Value of all the goods and services produced in a state over a 1-year period.

Growing-stock trees. Live trees of commercial species classified as sawtimber, poletimber, saplings, and seedlings; that is, all live trees of commercial species except rough and rotten trees.

Hardwoods. Dicotyledonous trees, usually broad leaved and deciduous.

Industry. A firm or group of firms that assemble inputs in a production process and produce an output or group of outputs.

Nonindustrial lands. Privately owned forested lands other than forest industry.

Population/employment ratio. Population/employment ratios are developed in the IMPLAN System by dividing the regional population by the total employment. This ratio is a determination of the number of dependents that are associated with an employee.

Sawlog. A log meeting regional standards of diameter, length, and defect, including a minimum 8-foot length and a minimum diameter inside bark of 6 inches for softwoods and 8 inches for hardwoods.

Sawtimber trees. Live trees of commercial species at least 9.0 inches d.b.h. for softwoods or 11.0 inches for hardwoods containing at least one 12-foot sawlog or two noncontiguous 8-foot sawlogs, and meeting regional specifications for freedom from defect.

Sawtimber volume. Net volume in board feet, International ¼-inch rule, of sawlogs in sawtimber trees. Net volume equals gross volume less deductions for rot, sweep, and other defects that affect use for lumber.

Sector. An industry or group of industries that is grouped together in an Input-Output model to reduce size of the model but that still accounts for all industries.

SIC Standard Industrial Classification codes used by the Bureau of Economic Analysis, U.S. Department of Commerce.

Stand-size class. A classification of forest land based on the size class (that is, seedlings, saplings, poletimber, or sawtimber) of growing-stock trees in the area.

Softwood. Coniferous trees, usually evergreen, with needles or scalelike leaves.

Timberland. Forest land producing or capable of producing crops of industrial wood and not withdrawn from timber utilization.

Timber removals. The growing-stock or sawtimber volumes of trees removed from the inventory for roundwood products, plus logging residues, volume destroyed during land clearing, and volume of standing trees growing on land that was reclassified from commercial forest land to noncommercial forest land.

Total final demand. Total final demand is the sum of personal consumption expenditures, capital formation, inventory change, state and local government expenditures, federal government expenditures and foreign exports. Except for foreign exports, these expenditures represent purchases by entities within the region from producing sectors both within and outside the region.

Total gross output. The value, in producer prices, of all outputs produced by the industries in a sector during 1977. Total gross output is the sum of all sales of an industry during a calendar year. It also includes net inventory change, which includes the value of outputs produced during the year and not sold, also the value of output in process at the end of the year minus the value of the output on hand and in process at the beginning of the year.

Total value added. The sum of employee compensation, indirect business taxes, rent, profits, interest, dividends, and depreciation expenses equals total value added. Value added is essentially the income accruing to society when an output is produced and sold.

Veneer log. A roundwood product from which veneer is sliced or sawed that usually meets certain minimum standards of diameter, length, and defect.

*** VERMONT IMPACT AREA ***
ALTERNATIVE 02: 2 BASE YEAR
ANALYSIS OF CHANGE IN FINAL DEMAND
TOTAL CHANGE IN STANDARD TGO-RELATED FLOWS

IMPACT REPORT #6.224
DATE 02/14/85
PAGE 01

	SECTOR	FINAL DEMAND (MM$)	TGO (MM$)	EMPLOYEE COMP INCOME (MM$)	PROPERTY INC (MM$)	TOTAL INCOME (MM$)	VALUE ADDED (MM$)	EMPLOYMENT (NUMBER OF JOBS)
1	AGG*AGRICULTURE & NURSER	.6099	3.0632	.3197	.7584	1.0781	1.1823	40.58
11	FORESTRY AND FISHERY PRO	.0970	2.6923	.5037	1.1543	1.6580	1.7088	66.48
12	AGRICULTURAL, FORESTRY,	.0088	.3228	.1106	.0370	.1476	.1540	14.52
29	AGG*STONE,SAND,GRAVEL	.0004	.1446	.0509	.0357	.0866	.0902	2.42
51	NEW CONSTRUCTION	.0000	.0000	.0000	.0000	.0000	.0000	.00
52	MAINTENANCE AND REPAIR C	.0000	2.5496	1.2411	.2043	1.4454	1.4546	50.11
56	AGG*SMALL ARMS	.0397	.0433	.0238	.0029	.0268	.0273	.79
59	AGG*FOOD PROCESSING	3.6761	5.7537	.7437	.1916	.9353	1.0594	51.61
107	AGG*TEXTILES & CLOTHES	1.5302	2.8970	.7159	.1558	.8717	.8885	79.48
136	LOGGING CAMPS AND LOGGIN	.0005	8.6035	1.0633	1.2417	2.3049	2.3910	151.06
137	AGG*PRIMARY SAWTIMBER US	15.4017	29.8874	6.7572	3.5516	10.3089	10.5550	700.21
140	AGG*SECONDARY SAWTIMBER	.0864	2.0286	.4711	.2433	.7144	.7336	61.89
142	VENEER AND PLYWOOD	9.8112	15.3681	3.4388	1.7556	5.1944	5.3161	327.31
150	WOOD HOUSEHOLD FURNITURE	69.3037	69.4582	23.7031	4.2571	27.9602	28.6458	2466.79
153	UPHOLSTERED HOUSEHOLD FU	.0011	.0011	.0003	.0001	.0004	.0004	.03
154	AGG*NON WOOD FURNITURE	.0494	.0596	.0168	.0029	.0196	.0201	1.53
163	AGG*PAPER PRODUCTS,	.3603	4.0133	.8459	.4754	1.3213	1.3632	52.28
176	AGG*PRINTING & PUBLISHIN	.6521	2.3907	.7887	.2833	1.0720	1.0936	65.17
191	AGG*NON METAL MFG	.5346	5.8658	1.6122	.5222	2.1343	2.2609	121.25
254	AGG*METAL MFG	.1209	2.3445	.6268	.2092	.8360	.8554	43.08
306	AGG*MACHINES,MACHINE TOO	.0386	.7687	.3146	.0689	.3835	.3934	22.63
336	AGG*ELEC & ELECTRONIC MF	.3680	.8350	.2901	.0729	.3630	.3701	17.88
376	AGG*TRANSPORTATION EQUIP	.2353	.3769	.1157	.0070	.1227	.1265	6.58
390	AGG*OTHER CONSUMER GOODS	.5940	.9418	.3561	.0619	.4180	.4252	27.04
420	AGG*TRANSPORTATION	1.4814	4.5505	1.8866	.6312	2.5178	2.7249	136.48
427	AGG*TELEPHONE,RADIO,TV	1.9824	3.8537	1.5801	1.1563	2.7364	3.0893	79.04
429	AGG*UTILITIES	2.6633	6.0621	.8866	1.5327	2.4192	2.8653	52.61
432	WHOLESALE TRADE	3.9571	9.9145	4.0615	1.8249	5.8864	7.3845	325.07
433	RETAIL TRADE	14.5330	14.9384	6.6921	2.5171	9.2092	11.6851	866.30
434	AGG*FINANCE & INSURANCE	4.1705	7.6283	2.8443	.8504	3.6947	4.0799	213.39
439	OWNER-OCCUPIED DWELLINGS	12.5747	12.5747	.0000	10.6654	10.6654	10.6654	.00
440	AGG*PROFESSIONAL & PERSO	5.5704	11.9217	2.9326	3.4051	6.3377	7.9654	247.61
441	HOTELS AND LODGING PLACE	.7896	1.0211	.3724	.1701	.5426	.5900	83.21
447	EATING AND DRINKING PLAC	5.6213	6.7530	2.1883	.2504	2.4387	2.8642	327.92
449	AGG*RECREATION SERVICES	1.0725	1.3697	.4176	.1829	.6005	.7587	105.77
451	AGG*MEDICAL & SOCIAL SER	8.7148	9.0736	5.1703	.6971	5.8673	5.9770	544.64
458	AGG*GOVERNMENT ENTERPRIS	.9902	2.0223	1.1702	.1426	1.3127	1.3178	76.09
466	SCRAP, USED, AND SECNDH	.2372	.3179	.0000	.0000	.0000	.0000	.00
	TOTAL	167.8784	252.4114	74.3126	39.3194	113.6320	123.0871	7428.86

CHANGE IN POPULATION = 23081.

*** VERMONT IMPACT AREA ***
ALTERNATIVE 03: 3 PLUS 20 PERCENT
ANALYSIS OF CHANGE IN FINAL DEMAND
TOTAL CHANGE IN STANDARD TGO-RELATED FLOWS

IMPACT REPORT #6.224
DATE 02/14/85
PAGE 01

	SECTOR	FINAL DEMAND (MM$)	TGO (MM$)	EMPLOYEE COMP INCOME (MM$)	PROPERTY INC (MM$)	TOTAL INCOME (MM$)	VALUE ADDED (MM$)	EMPLOYMENT (NUMBER OF JOBS)
1	AGG*AGRICULTURE & NURSER	.7381	3.7009	.3863	.9163	1.3026	1.4284	49.03
11	FORESTRY AND FISHERY PRO	.1174	3.2205	.6026	1.3808	1.9833	2.0440	79.53
12	AGRICULTURAL, FORESTRY,	.0107	.3895	.1335	.0446	.1781	.1859	17.52
29	AGG*STONE,SAND,GRAVEL	.0005	.1753	.0617	.0433	.1049	.1094	2.94
51	NEW CONSTRUCTION	.0000	.0000	.0000	.0000	.0000	.0000	.00
52	MAINTENANCE AND REPAIR C	.0000	3.0827	1.5006	.2471	1.7476	1.7588	60.59
56	AGG*SMALL ARMS	.0480	.0524	.0288	.0036	.0324	.0330	.96
59	AGG*FOOD PROCESSING	4.4492	6.9630	.9000	.2318	1.1319	1.2821	62.46
107	AGG*TEXTILES & CLOTHES	1.8521	3.5088	.8671	.1887	1.0558	1.0762	96.26
136	LOGGING CAMPS AND LOGGIN	.0006	10.2850	1.2711	1.4844	2.7554	2.8583	180.58
137	AGG*PRIMARY SAWTIMBER US	18.3770	35.9394	8.1255	4.2708	12.3964	12.6923	842.00
140	AGG*SECONDARY SAWTIMBER	.1045	2.4666	.5728	.2959	.8686	.8920	75.25
142	VENEER AND PLYWOOD	11.4464	18.1262	4.0560	2.0707	6.1267	6.2702	386.05
150	WOOD HOUSEHOLD FURNITURE	84.3676	84.5556	28.8552	5.1824	34.0377	34.8722	3002.97
153	UPHOLSTERED HOUSEHOLD FU	.0013	.0014	.0004	.0001	.0005	.0005	.04
154	AGG*NON WOOD FURNITURE	.0598	.0722	.0203	.0035	.0238	.0244	1.85
163	AGG*PAPER PRODUCTS,	.4361	4.8703	1.0266	.5769	1.6035	1.6543	63.44
176	AGG*PRINTING & PUBLISHIN	.7892	2.8951	.9550	.3431	1.2981	1.3243	78.92
191	AGG*NON METAL MFG	.6470	7.1123	1.9548	.6331	2.5879	2.7414	147.02
254	AGG*METAL MFG	.1463	2.8341	.7577	.2529	1.0106	1.0340	52.08
306	AGG*MACHINES,MACHINE TOO	.0468	.9299	.3805	.0834	.4639	.4758	27.38
336	AGG*ELEC & ELECTRONIC MF	.4454	1.0106	.3511	.0882	.4393	.4479	21.64
376	AGG*TRANSPORTATION EQUIP	.2848	.4557	.1399	.0085	.1484	.1530	7.95
390	AGG*OTHER CONSUMER GOODS	.7190	1.1405	.4313	.0750	.5062	.5150	32.74
420	AGG*TRANSPORTATION	1.7930	5.5042	2.2820	.7635	3.0456	3.2960	165.69
427	AGG*TELEPHONE,RADIO,TV	2.3994	4.6656	1.9129	1.3999	3.3129	3.7400	95.69
429	AGG*UTILITIES	3.2235	7.3338	1.0725	1.8542	2.9267	3.4664	63.65
432	WHOLESALE TRADE	4.7893	12.0007	4.9160	2.2089	7.1250	8.9384	393.46
433	RETAIL TRADE	17.5895	18.0795	8.0992	3.0464	11.1456	14.1470	1048.45
434	AGG*FINANCE & INSURANCE	5.0477	9.2323	3.4424	1.0293	4.4717	4.9378	258.26
439	OWNER-OCCUPIED DWELLINGS	15.2194	15.2194	.0000	12.9085	12.9085	12.9085	.00
440	AGG*PROFESSIONAL & PERSO	6.7420	14.4275	3.5490	4.1208	7.6698	9.6396	299.65
441	HOTELS AND LODGING PLACE	.9557	1.2357	.4507	.2059	.6566	.7140	100.70
447	EATING AND DRINKING PLAC	6.8035	8.1737	2.6487	.3031	2.9517	3.4668	396.90
449	AGG*RECREATION SERVICES	1.2980	1.6578	.5055	.2214	.7268	.9182	128.02
451	AGG*MEDICAL & SOCIAL SER	10.5477	10.9819	6.2576	.8437	7.1013	7.2340	659.18
458	AGG*GOVERNMENT ENTERPRIS	1.1984	2.4475	1.4162	.1725	1.5887	1.5948	92.09
466	SCRAP, USED, AND SECONDH	.2871	.3847	.0000	.0000	.0000	.0000	.00
	TOTAL	202.9821	305.1322	89.9315	47.5029	137.4344	148.8750	8990.35

CHANGE IN POPULATION = 27932.

*** VERMONT IMPACT AREA ***
ALTERNATIVE 04: 4 MINUS 20 PERCENT
ANALYSIS OF CHANGE IN FINAL DEMAND
TOTAL CHANGE IN STANDARD TGO-RELATED FLOWS

IMPACT REPORT #6.224
DATE 02/14/85
PAGE 01

	SECTOR	FINAL DEMAND (MM$)	TGO (MM$)	EMPLOYEE COMP INCOME (MM$)	PROPERTY INC (MM$)	TOTAL INCOME (MM$)	VALUE ADDED (MM$)	EMPLOYMENT (NUMBER OF JOBS)
1	AGG*AGRICULTURE & NURSER	.4920	2.4669	.2575	.6108	.8683	.9521	32.68
11	FORESTRY AND FISHERY PRO	.0783	2.1470	.4017	.9205	1.3222	1.3627	53.02
12	AGRICULTURAL, FORESTRY,	.0071	.2596	.0890	.0297	.1187	.1239	11.68
29	AGG*STONE,SAND,GRAVEL	.0004	.1168	.0411	.0289	.0700	.0729	1.96
51	NEW CONSTRUCTION	.0000	.0000	.0000	.0000	.0000	.0000	.00
52	MAINTENANCE AND REPAIR C	.0000	2.0549	1.0003	.1647	1.1649	1.1724	40.39
56	AGG*SMALL ARMS	.0320	.0350	.0192	.0024	.0216	.0220	.64
59	AGG*FOOD PROCESSING	2.9657	4.6412	.5999	.1545	.7544	.8546	41.64
107	AGG*TEXTILES & CLOTHES	1.2345	2.3389	.5780	.1258	.7038	.7173	64.17
136	LOGGING CAMPS AND LOGGIN	.0004	6.8567	.8474	.9896	1.8369	1.9055	120.39
137	AGG*PRIMARY SAWTIMBER US	12.2514	23.9596	5.4170	2.8472	8.2642	8.4615	561.33
140	AGG*SECONDARY SAWTIMBER	.0697	1.6444	.3818	.1972	.5791	.5947	50.16
142	VENEER AND PLYWOOD	7.6309	12.0841	2.7040	1.3805	4.0844	4.1801	257.37
150	WOOD HOUSEHOLD FURNITURE	56.2450	56.3704	19.2368	3.4549	22.6918	23.2481	2001.98
153	UPHOLSTERED HOUSEHOLD FU	.0009	.0009	.0003	.0000	.0003	.0003	.03
154	AGG*NON WOOD FURNITURE	.0399	.0481	.0135	.0023	.0159	.0163	1.23
163	AGG*PAPER PRODUCTS.	.2907	3.2466	.6843	.3846	1.0689	1.1028	42.29
176	AGG*PRINTING & PUBLISHIN	.5260	1.9298	.6366	.2287	.8653	.8828	52.61
191	AGG*NON METAL MFG	.4313	4.7413	1.3031	.4221	1.7252	1.8275	98.01
254	AGG*METAL MFG	.0975	1.8894	.5051	.1686	.6737	.6893	34.72
306	AGG*MACHINES,MACHINE TOO	.0312	.6199	.2537	.0556	.3092	.3172	18.25
336	AGG*ELEC & ELECTRONIC MF	.2969	.6737	.2340	.0588	.2928	.2986	14.43
376	AGG*TRANSPORTATION EQUIP	.1898	.3038	.0933	.0056	.0989	.1020	5.30
390	AGG*OTHER CONSUMER GOODS	.4792	.7602	.2875	.0500	.3374	.3433	21.83
420	AGG*TRANSPORTATION	1.1951	3.6691	1.5212	.5090	2.0302	2.1971	110.05
427	AGG*TELEPHONE,RADIO,TV	1.5993	3.1100	1.2751	.9332	2.2083	2.4930	63.79
429	AGG*UTILITIES	2.1486	4.8885	.7149	1.2360	1.9509	2.3106	42.43
432	WHOLESALE TRADE	3.1923	7.9997	3.2771	1.4725	4.7495	5.9584	262.29
433	RETAIL TRADE	11.7243	12.0509	5.3986	2.0306	7.4292	9.4257	698.85
434	AGG*FINANCE & INSURANCE	3.3645	6.1540	2.2946	.6861	2.9807	3.2914	172.15
439	OWNER-OCCUPIED DWELLINGS	10.1445	10.1445	.0000	8.6042	8.6042	8.6042	.00
440	AGG*PROFESSIONAL & PERSO	4.4939	9.6171	2.3657	2.7468	5.1125	6.4256	199.74
441	HOTELS AND LODGING PLACE	.6370	.8237	.3004	.1372	.4377	.4760	67.12
447	EATING AND DRINKING PLAC	4.5349	5.4483	1.7655	.2020	1.9675	2.3108	264.56
449	AGG*RECREATION SERVICES	.8652	1.1050	.3369	.1476	.4845	.6121	85.33
451	AGG*MEDICAL & SOCIAL SER	7.0306	7.3200	4.1711	.5623	4.7334	4.8219	439.38
458	AGG*GOVERNMENT ENTERPRIS	.7988	1.6314	.9440	.1150	1.0590	1.0631	61.39
466	SCRAP, USED, AND SECONDH	.1914	.2564	.0000	.0000	.0000	.0000	.00
	TOTAL	135.3113	203.4081	59.9502	31.6654	91.6157	99.2418	5993.16
	CHANGE IN POPULATION =	18620.						

*** VERMONT IMPACT AREA ***
ALTERNATIVE 05: 5 50 % PROG GROW 1995
ANALYSIS OF CHANGE IN FINAL DEMAND
TOTAL CHANGE IN STANDARD TGO-RELATED FLOWS

IMPACT REPORT #6.224
DATE 02/14/85
PAGE 01

	SECTOR	FINAL DEMAND (MM$)	TGO (MM$)	EMPLOYEE COMP INCOME (MM$)	PROPERTY INC (MM$)	TOTAL INCOME (MM$)	VALUE ADDED (MM$)	EMPLOYMENT (NUMBER OF JOBS)
1	AGG*AGRICULTURE & NURSER	1.3630	6.8350	.7134	1.6923	2.4056	2.6380	90.55
11	FORESTRY AND FISHERY PRO	.2168	5.9545	1.1141	2.5529	3.6670	3.7793	147.04
12	AGRICULTURAL, FORESTRY,	.0197	.7195	.2465	.0824	.3289	.3433	32.36
29	AGG*STONE,SAND,GRAVEL	.0010	.3236	.1138	.0799	.1938	.2019	5.42
51	NEW CONSTRUCTION	.0000	.0000	.0000	.0000	.0000	.0000	.00
52	MAINTENANCE AND REPAIR C	.0000	5.6930	2.7712	.4562	3.2274	3.2480	111.90
56	AGG*SMALL ARMS	.0887	.0968	.0532	.0066	.0598	.0610	1.78
59	AGG*FOOD PROCESSING	8.2154	12.8572	1.6619	.4281	2.0900	2.3674	115.34
107	AGG*TEXTILES & CLOTHES	3.4198	6.4784	1.6009	.3484	1.9493	1.9869	177.73
136	LOGGING CAMPS AND LOGGIN	.0012	19.0176	2.3503	2.7447	5.0949	5.2851	333.90
137	AGG*PRIMARY SAWTIMBER US	33.9538	66.3721	15.0060	7.8873	22.8933	23.4359	1554.98
140	AGG*SECONDARY SAWTIMBER	.1930	4.5520	1.0570	.5460	1.6031	1.6462	138.86
142	VENEER AND PLYWOOD	21.2576	33.6059	7.5198	3.8391	11.3588	11.6249	715.74
150	WOOD HOUSEHOLD FURNITURE	155.6787	156.0257	53.2449	9.5628	62.8078	64.3478	5541.21
153	UPHOLSTERED HOUSEHOLD FU	.0024	.0025	.0008	.0001	.0009	.0009	.08
154	AGG*NON WOOD FURNITURE	.1105	.1333	.0375	.0064	.0439	.0450	3.42
163	AGG*PAPER PRODUCTS.	.8053	8.9901	1.8950	1.0649	2.9598	3.0537	117.10
176	AGG*PRINTING & PUBLISHIN	1.4572	5.3454	1.7633	.6335	2.3968	2.4452	145.71
191	AGG*NON METAL MFG	1.1947	13.1306	3.6089	1.1689	4.7777	5.0611	271.42
254	AGG*METAL MFG	.2702	5.2337	1.3992	.4671	1.8663	1.9095	96.17
306	AGG*MACHINES,MACHINE TOO	.0864	1.7171	.7026	.1539	.8565	.8786	50.55
336	AGG*ELEC & ELECTRONIC MF	.8223	1.8660	.6483	.1629	.8112	.8271	39.96
376	AGG*TRANSPORTATION EQUIP	.5259	.8416	.2584	.0157	.2741	.2825	14.69
390	AGG*OTHER CONSUMER GOODS	1.3276	2.1058	.7962	.1384	.9347	.9508	60.45
420	AGG*TRANSPORTATION	3.3108	10.1640	4.2140	1.4099	5.6239	6.0864	304.85
427	AGG*TELEPHONE,RADIO,TV	4.4304	8.6145	3.5321	2.5848	6.1169	6.9056	176.69
429	AGG*UTILITIES	5.9521	13.5422	1.9805	3.4239	5.4044	6.4009	117.54
432	WHOLESALE TRADE	8.8434	22.1586	9.0772	4.0786	13.1559	16.5042	726.51
433	RETAIL TRADE	32.4786	33.3834	14.9551	5.6251	20.5802	26.1222	1935.95
434	AGG*FINANCE & INSURANCE	9.3204	17.0473	6.3563	1.9005	8.2568	9.1175	476.87
439	OWNER-OCCUPIED DWELLINGS	28.1022	28.1022	.0000	23.8353	23.8353	23.8353	.00
440	AGG*PROFESSIONAL & PERSO	12.4489	26.6400	6.5531	7.6085	14.1620	17.7993	553.30
441	HOTELS AND LODGING PLACE	1.7646	2.2817	.8322	.3802	1.2124	1.3185	185.94
447	EATING AND DRINKING PLAC	12.5626	15.0924	4.8907	.5596	5.4503	6.4013	732.86
449	AGG*RECREATION SERVICES	2.3968	3.0611	.9333	.4088	1.3421	1.6955	236.38
451	AGG*MEDICAL & SOCIAL SER	19.4760	20.2777	11.5546	1.5578	13.1123	13.3574	1217.17
458	AGG*GOVERNMENT ENTERPRIS	2.2129	4.5193	2.6150	.3186	2.9336	2.9448	170.04
466	SCRAP, USED, AND SECONDH	.5301	.7103	.0000	.0000	.0000	.0000	.00
	TOTAL	374.8407	563.4922	166.0574	87.7304	253.7877	274.9130	16600.47
	CHANGE IN POPULATION =	51576.						

*U.S. GOVERNMENT PRINTING OFFICE: 1986 - 606-

Michaels, Joseph A.; Stone, M. Brian; Sendak, Paul E. **The economic importance of Vermont's sawtimber.** NE-RP-587. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1986. 12 p.

This paper concentrates on the potential economic importance of Vermont's sawtimber. The timber industry employed over 9,000 workers in 1980, and the value of stumpage cut that year was worth approximately $459 million to the State's economy. Preliminary resurvey data indicate that sawtimber inventory now exceeds 14 billion board feet. Yet, sawtimber removals have averaged only 200 million board feet per year over the last 10 years. We used an input-output model called IMPLAN V1.1 to predict socio-economic impacts of several sawtimber production levels. The results indicate that improved markets for the existing resource could significantly contribute to the State's economy. If 50 percent of the projected annual growth could be marketed, an additional $152 million contribution could be made to the State's gross product and over 9,000 new jobs created.

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Research Paper
NE–588

1986

Comparison of Glue-Line Quality Between Gang Edging and Straight-Line Ripping

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Manuscript received for publication 21 January 1986.

Abstract

Gang edging with a dip-chain fed gang ripsaw produces gluing surfaces equal to those from a straight-line ripsaw in yellow-poplar (*Liriodendron tulipifera*) and red oak (*Quercus rubra*). Special care in gluing red oak was needed to get shear strengths equal to solid wood values. However, the strength comparisons between sawing methods showed no differences between gang edging and straight-line ripping regardless of gluing procedures.

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Introduction

Gang ripping can be used with No. 2 Common lumber to produce more long lengths than the furniture and cabinet industries need (Gatchell et al. 1983, Gatchell 1986, Araman et al. 1982). Gang edging (gang ripsaw arbor set with several pairs of blades at varied spacing) is a key step in the utilization of small-diameter logs for furniture and cabinets through the new System 6 process (Reynolds and Gatchell 1982). Gang edging or gang ripping to glue-line quality edges is required in System 6 and is desirable in the design of new manufacturing sequences for the conversion of lower grades of lumber.

Some potential users of the new System 6 technology have questioned whether the surfaces from gang edging were of comparable quality to the state-of-the-art edges made on the straight-line ripsaw. The general feeling was that gang edging to glue-line quality surfaces might not be possible for the more dense hardwoods. The basic question was whether the wood could be held securely enough during sawing to produce the quality needed. This study was conducted to determine whether a dip-chain fed gang saw could produce glue lines of strengths comparable to those from a straight-line ripsaw.

Materials and Methods

A dip-chain fed gang edger and a straight-line ripsaw were used. The gang edger was a conventional dip-chain fed gang ripsaw set up with five pairs of saws to cut widths from 1½ to 3½ inches in ½-inch increments (Fig. 1). In each pair the right-hand saw was used to make a hogging cut. Each hogging saw blade was made from 0.254-inch-thick steel plate and had a 5/16-inch saw kerf. The left-hand gang edger blades and the straight-line ripsaw blades were made from 0.134-inch-thick plate with a 3/16-inch saw kerf.

Saws in each machine ran at about 3,500 r/min (revolutions per minute). The gang edger had 12-inch diameter saw blades with 30 carbide-tipped teeth per blade and a feed speed of 58 ft/min (feet per minute). The saw tooth hook angle was 20 degrees. The straight-line ripsaw blade was 14

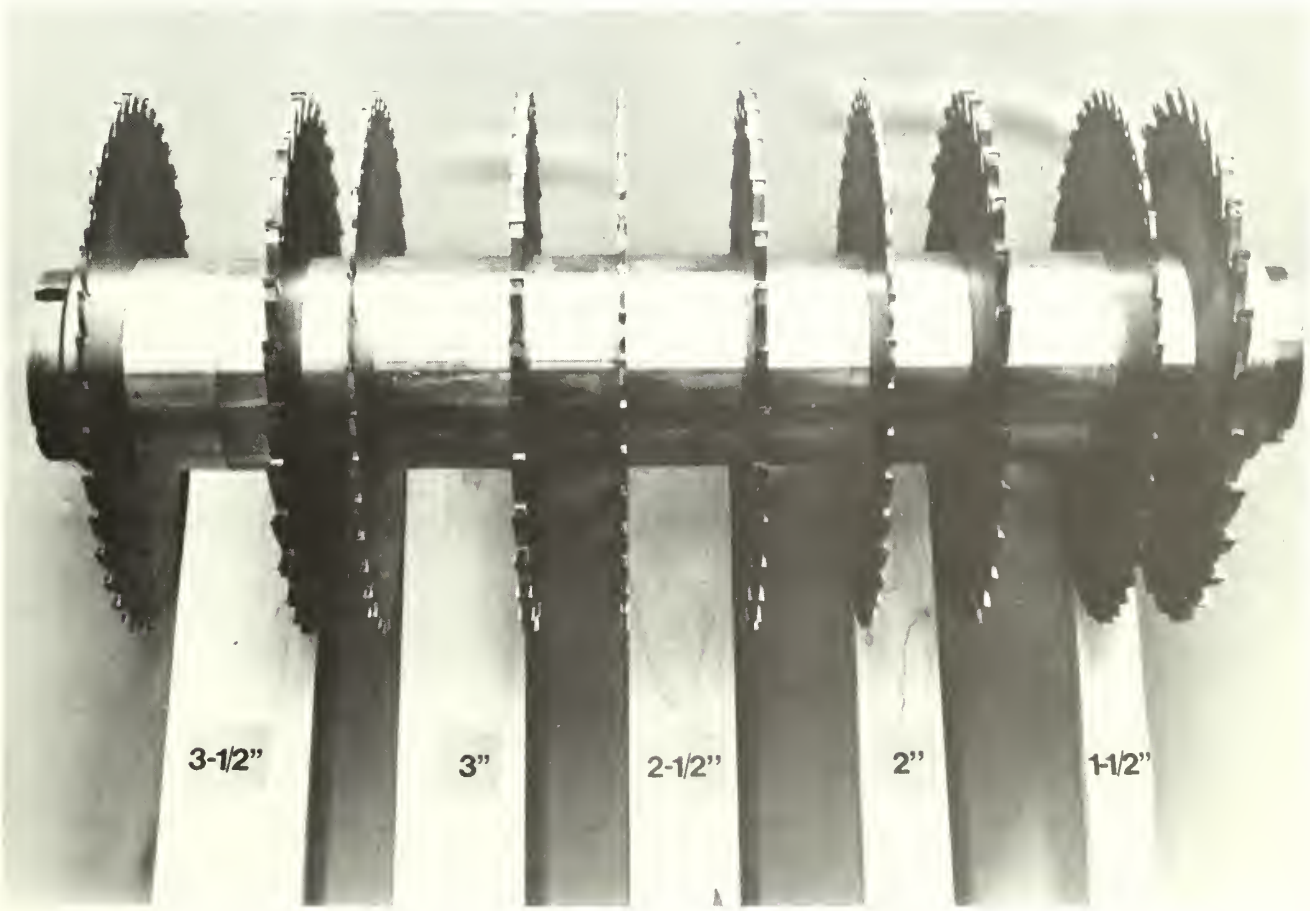

Figure 1.—The arbor of the dip-chain fed gang edger contains five pairs of blades.

inches in diameter with 36 carbide-tipped teeth, and the feed speed was 65 ft/min. The hook angle was 10 degrees. The combination of feed speed, saw diameter, number of saw teeth, and saw r/min resulted in a bite per tooth for all blades of 0.007 inch.

The analysis of glue-line strength was based on two separate studies. The first approximated our routine panel lay-up procedures. We made panels of three lengths containing pieces of three different widths sawed from lumber taken at random from an existing supply. A diffuse porous hardwood, yellow-poplar—*Liriodendron tulipifera*, and a ring porous hardwood, northern red oak—*Quercus rubra*, were used. When the results showed about a 20 percent reduction in shear strength between solid wood and glued-up panels in oak, a second study was run. The second study was very closely controlled and attempts were made to ensure that each panel was constructed as identically as possible with all others. All panels in both studies were glued using the same room-temperature setting polyvinyl acetate adhesive.

Study One—Routine Panel Lay-up Procedures

To compare glue lines from the gang edger and straight-line ripsaws with routine panel lay-up procedures, edges were prepared with each machine and included in each panel as shown in Figure 2. We ran enough pieces of ¼ yellow-poplar and red oak rough dimension, at about 7 percent moisture content, through the gang edger to lay up 24-inch-wide panels in combinations of 1½-, 2½-, and 3½-inch-wide pieces. To produce the straight-line ripped edge, gang edged pieces were randomly selected and a rip cut was made about ¼ inch in from one edge. Panel lengths were 21, 33, and 60 inches. We made enough panels so that each piece width group was glued up first, second, or last in the lay-up sequence. Each of these arrangements was replicated twice. Thirty-six panels were made (2 species × 3 lengths × 3 lay-up sequences × 2 replications).

In laying up the panels, glue was applied with a flexible stick that produced a thick, bubble-free glue spread. Glue was applied to only one side of the glue line. Pieces were layed up with the first and last pieces directly in contact with the glue clamps. A pressure of 200 lb/in^2 (pounds per square inch) at the glue line was applied, and panels were left in the clamps for at least 1½ hours. The finished panels were cured for at least 2 weeks before samples were taken for testing.

The block shear test (ASTM 1984) was modified since testing was restricted by the thickness of the panels. The panels were first sanded to 0.75 inch. The block shear sample dimensions we used are shown in Figure 3. The shearing cross section was 0.75 × 1.5 inches or 1.125 square inches. Three, five, and seven shear block samples were taken from each of the 21-, 33-, and 60-inch test glue lines,

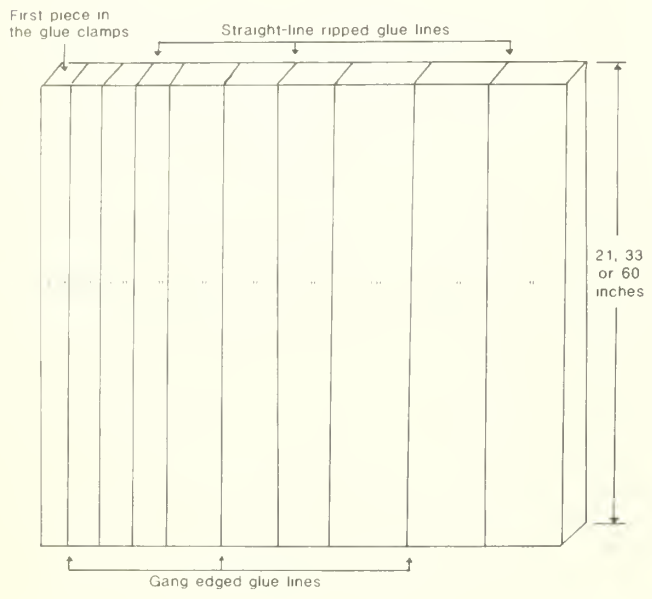

Figure 2.—Study One blank layout sequence 1. Sequence 2 had the 1½-inch strips on the right side (layed up last) of the panel. Sequence 3 had the 3½-inch-wide strips layed up first and the 2½-inch strips layed up last.

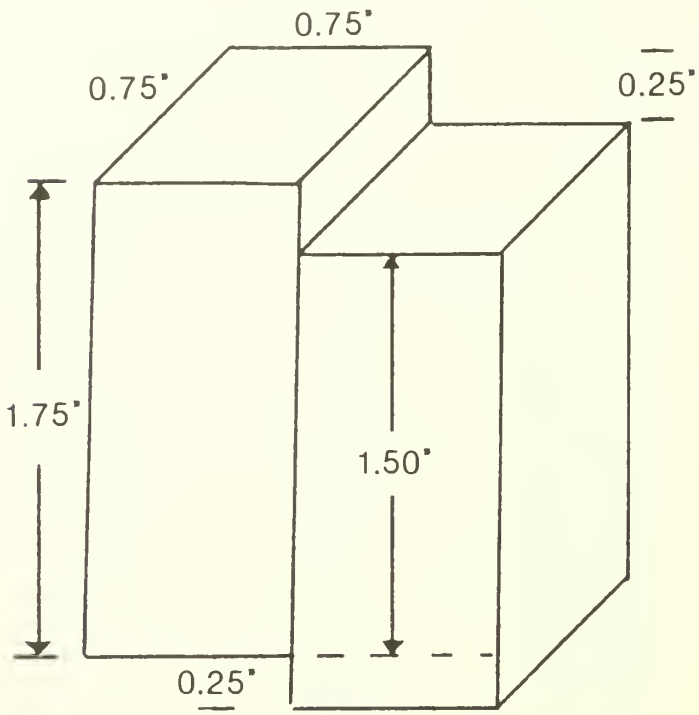

Figure 3.—Dimension of the block shear samples.

respectively. Samples were removed at positions equidistant from the panels' ends and from each other along the glue line. An equivalent number of solid wood samples were taken along two of the panel's 3½-inch strips.

The block shear samples were placed into a constant temperature (70°F)-humidity (66 percent) cabinet until a constant weight was obtained. A standard shearing tool was used to test the maximum load at failure for each sample at a head speed of 0.02 inch per minute. Maximum shear strength in pounds per square inch was determined for each block shear sample. Moisture content was determined immediately after shear testing.

Study One—Results and Discussion

A preliminary examination of the data for individual samples showed that there was no loss in shear strength across the width of the panels due to lay-up procedures. Thus, even though it takes almost 3 times as long with our techniques to spread the glue on a 60-inch-long piece as on a 21-inch-long piece, our procedures were adequate for good glue bond formation.

Average shear strength values for red oak and yellow-poplar are given in Table 1. Moisture content at the time of test was about 11 percent. A statistical analysis showed no significant difference between glue joints prepared with either the straight-line ripsaw or the gang edger. There was also no significant difference between the pairs of blades in the 1½-, 2½-, or 3½-inch bays of the gang edger.

As expected, the red oak shear strength values were higher than those for yellow-poplar. The values for the glued-up and solid wood yellow-poplar samples were about the same reflecting the more uniform nature (diffuse porous with thin rays) of this less dense wood. We did not, however, expect to find a 20 percent strength reduction when comparing red oak glued samples to solid wood samples. There may have been an interaction of small shear block size and the weakening effects of pronounced earlywood vessels or large rays that are typical of red oak. There was no increasing or decreasing trend in the strengths of individual samples as we proceeded from the first glue line to the last glue line in a panel. Thus, if there was some machining, gluing, or testing procedural error, it was consistent enough not to show up in the comparisons of the two sawing methods.

As the glue-line preparation procedures were considered equivalent for the two sawing methods (gang edging and straight-line ripping), all values for each method were averaged to obtain indicator values with standard deviations for length (Table 2). We include standard deviations in Table 2 to give the reader an appreciation for the variability of the

Table 1.—Average shear strength values for red oak and yellow-poplar wood and glue lines

Species	Panel length	Strip width	Gang edger[a]	Straight-line ripsaw[a]	Solid wood[b]
	Inches	*Inches*	*Average shear strength (lb/in²)*		
Red oak	21	1.5	1,788	1,901	2,301
		2.5	1,693	1,798	2,301
		3.5	1,812	1,891	2,301
	33	1.5	1,635	1,622	2,088
		2.5	1,640	1,720	2,088
		3.5	1,632	1,670	2,088
	60	1.5	1,632	1,559	2,087
		2.5	1,659	1,739	2,087
		3.5	1,645	1,581	2,087
Yellow-poplar	21	1.5	1,291	1,240	1,367
		2.5	1,295	1,267	1,367
		3.5	1,286	1,310	1,367
	33	1.5	1,302	1,300	1,320
		2.5	1,323	1,301	1,320
		3.5	1,321	1,333	1,320
	60	1.5	1,260	1,201	1,284
		2.5	1,286	1,332	1,284
		3.5	1,289	1,295	1,284

[a]Glue-line averages for the 21-, 33-, and 60-inch panel lengths were determined from 18, 30, or 42 block shear samples, respectively.
[b]Solid wood averages for the 21-, 33-, and 60-inch panel lengths were determined from 36, 60, or 84 block shear samples, respectively.

Table 2.—Study one—shear strength average values for red oak and yellow-poplar glued-up and wood samples (standard deviation in parentheses)

Species	Panel length	Gang edger[a]	Straight-line ripsaw[a]	Solid wood[b]
	Inches	*Average shear strength (lb/in²)*		
Red oak	21	1,765(226)	1,863(171)	2,301(260)
	33	1,636(174)	1,669(171)	2,080(192)
	60	1,647(208)	1,626(238)	2,087(278)
Yellow-poplar	21	1,291(133)	1,279(139)	1,367(155)
	33	1,315(176)	1,312(146)	1,320(179)
	60	1,269(168)	1,272(158)	1,284(256)

[a]Glue-line averages for the 21-, 33-, and 60-inch panel lengths were determined from 54, 90, or 126 block shear samples, respectively.
[b]Solid wood averages for the 21-, 33-, and 60-inch panel lengths were determined from 36, 60, or 84 block shear samples, respectively.

data. Ninety-five percent of all individual sample values will be within plus or minus 2 times the standard deviation. Larger deviations, therefore, show a wider range of values. The results clearly show that the dip-chain fed gang edger produces glue lines in oak and yellow-poplar that are equivalent to those obtained from a straight-line ripsaw. In oak, the 33- and 60-inch average shear strength values were very similar. The averages for the 21-inch panels were higher, but this was attributed to the higher average shear strength for the wood from which they were made. The averages for the yellow-poplar glued-up samples were very similar, ranging from 1,269 to 1,315 lb/in^2.

Study Two—Close Production Control

Because the red oak glued samples in Study One were 20 percent lower in average shear strength than the solid wood samples, a partial retest was done under close production control. Boards from an available kiln-dried red oak lumber supply were selected for straightness of grain and 4-inch-wide strips were sawed out. These were crosscut to pieces 33 inches long and passed through the 3-inch-wide pair of saws. Each panel contained three pieces, two of which were re-edged on the straight-line ripsaw and glued together. The other glue line was made from gang-edged surfaces. Panel construction is given in Table 3. Ten panels were glued up as shown in Figure 4 using the following procedures for each:

Table 3.—Study two—shear strength of glued up and solid red oak samples, in pounds per square inch

Panel No.	Panel construction			Glue joint preparation				Solid wood	
				Gang edger		Straight-line ripsaw			
	3 pieces same strip	3 pieces same board	Random pieces	Average[b]	Standard deviation	Average[b]	Standard deviation	Average[c]	Standard deviation
5	*			2,233	376	2,374	242	2,253	400
2	*			2,412	142	2,265	124	2,253	378
3[a]		*		2,161	334	2,192	270	2,402	274
4[a]		*		2,418	224	2,154	98	2,402	274
1		*		2,302	263	2,254	280	2,287	373
6		*		2,329	211	1,817	271	2,283	444
7			*	2,205	245	2,369	253	2,367	302
8			*	2,100	198	2,019	498	2,248	471
9			*	1,993	312	1,890	199	2,056	599
10			*	2,012	113	1,864	483	2,223	481

[a]Panels 3 and 4 were made from six pieces from one board. Therefore, a single mean and standard deviation based on 34 samples were computed for the solid wood from both.
[b]Average of seven values.
[c]Average of 17 values.

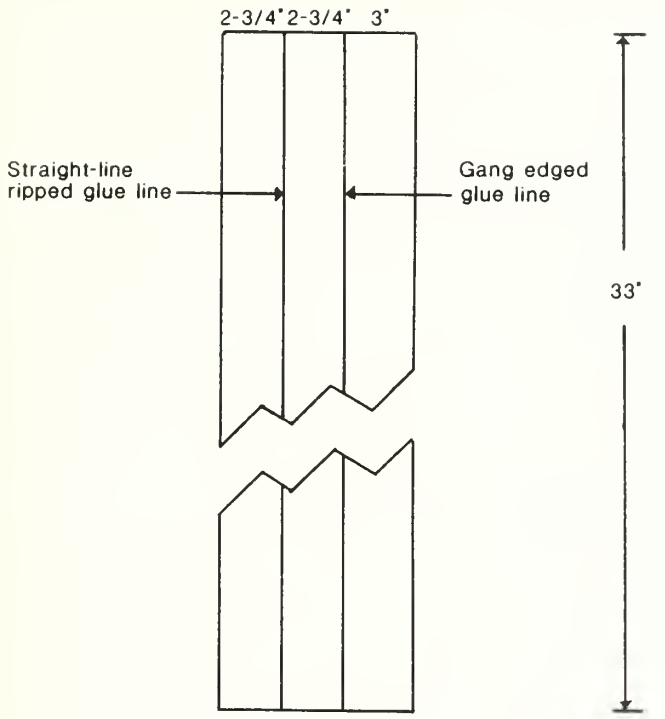

Figure 4.—Study Two blank layout.

1. Edges were prepared by sawing.
2. Within 10 minutes of sawing, glue was applied with flexible sticks to achieve a thick, continuous, bubble-free spread on one side of the glue line.
3. Square steel tubing was used between the glue clamps and the outside panel edges to ensure even pressure distribution.
4. A 1-minute closed assembly time was employed before application of 200 lb/in^2 clamp pressure.
5. Clamp time equaled 1 hour 30 minutes.

The next panel was begun only after the preceding panel was in the glue clamps. The panels were cured for at least 1 week before surfacing and for at least 2 weeks after surfacing before shear samples were prepared. The average moisture content at the time of testing was 8.5 percent.

Study Two—Results and Discussion

The shear strength value averages and standard deviations for the close production control red oak samples are given in Table 3. A statistical analysis showed no significant differences among the panels or between the dip-chain fed gang edger and the straight-line ripsaw at the 5 percent significance level.

In general, the greatest variability occurred in the solid wood samples. Rays formed a plane of weakness in one direction and earlywood vessels formed a plane of weakness at right angles to the rays. The thin (0.75 inch) samples gave these planes unusual importance when the plane of shear was lined up with either rays or earlywood. Figure 5 shows two solid wood samples taken a few inches apart along the grain from the same piece of wood. Sample 5-10C was the weakest sample of the entire study with a shear strength of 745 lb/in^2. About three-fourths of the failure surface was in or on both sides of a single ray. Sample 5-9C was taken from the same strip of wood just a few inches away. The orientation of the rays appeared to angle out of the shear plane enough so that other wood elements were brought into play. The result was a shear strength of 2,587 lb/in^2, one of the higher values of the study.

Figure 6 shows characteristic failure of solid wood (no glue line) samples when the rays and shear plane are not aligned. The failure shown has run out to the unsupported end of the sample. The saw tooth appearance of the broken surface is the result of failure going across a growth ring at or very near a ray, then turning at right angles along the earlywood of the next growth ring before again turning at right angles along another ray. In studies such as this, a predetermined orientation of the growth rings to the shear plane is not possible. It is a source of variation that is worth mentioning, however.

The solid wood and glued-up average shear strength values were about the same in Study Two. These averages were:

	Shear strength (lb/in^2)	
	Average	*Standard deviation*
Gang edger	2,217	280
Straight-line rip	2,120	343
Solid wood	2,268	441

As a comparison of the standard deviations shows, the glued-up samples varied less than did the solid wood samples. This was not entirely unexpected. As mentioned earlier, a ray or a zone of earlywood vessels contained in most or all of the plane of failure will cause low strength values. The chance of this occurring when two different pieces of wood are bonded together is considered to be far less likely than when solid wood pieces alone are considered. In a practical sense, we cannot really do better than equal the properties of the wood itself.

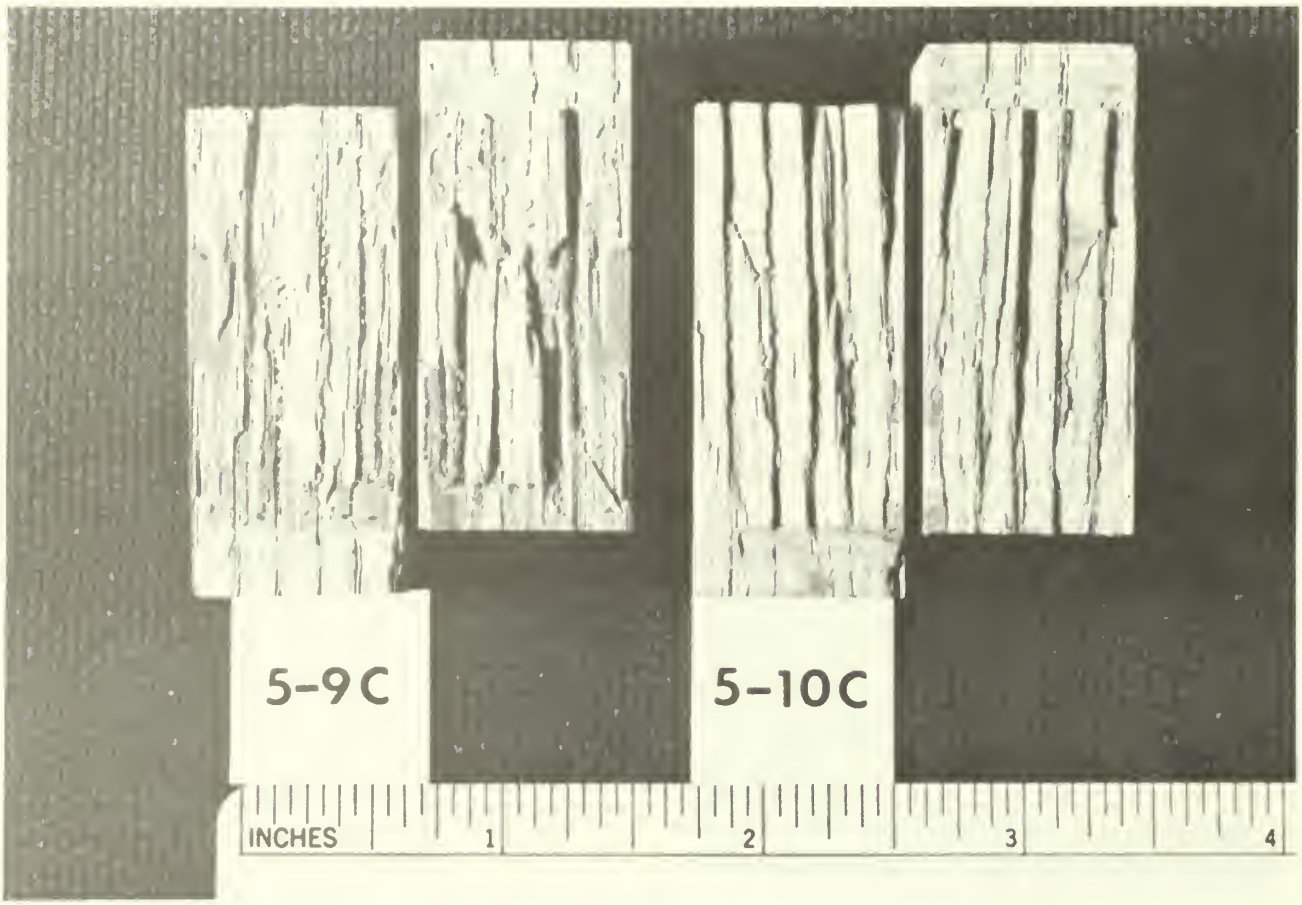

Figure 5.—One of the strongest (5-9C) and the weakest (5-10C) solid wood samples came from the same piece of wood and were only a few inches apart along the grain.

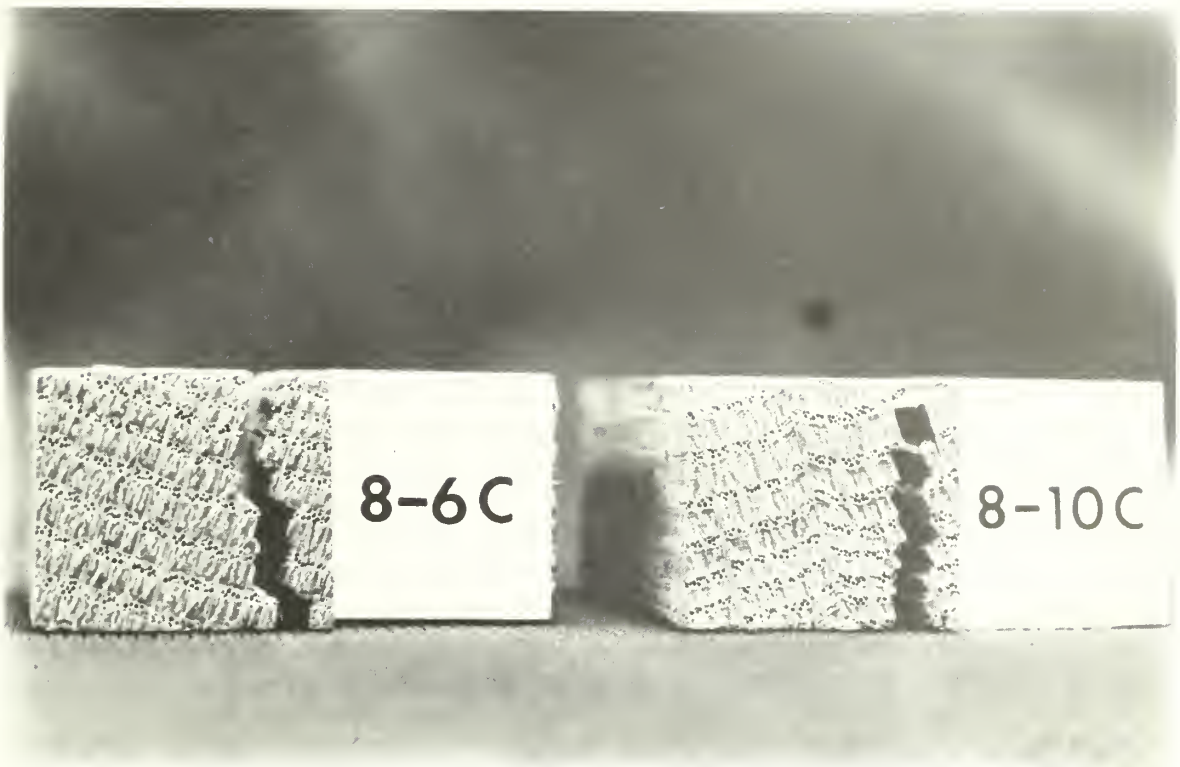

Figure 6.—Shear failure tends to run along rays and in the earlywood vessel zone giving a saw-toothed appearance to the failure on the unsupported end (label covers supported end of shear sample).

Summary

To be able to gang rip lumber to glue-line-quality edges is an important hardwood processing capability. The dip-chain fed gang edger or gang ripsaw is superior to roller fed gang saws in holding wood stock steady during sawing. However, potential users have questioned whether the dip-chain fed saw can produce glue-line surfaces equal in quality to those from a state-of-the-art straight-line ripsaw when machining hardwoods. The results of this study clearly show that these saws produce glue joints of equal strength in yellow-poplar and red oak in lengths from 21 to 60 inches.

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Gatchell, Charles J.; Olson, James R. **Comparison of glue-line quality between gang edging and straight-line ripping.** Res. Pap. NE-588 Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1986. 7 p.

Gang edging with a dip-chain fed gang ripsaw produces gluing surfaces equal to those from a straight-line ripsaw in yellow-poplar (*Liriodendron tulipifera*) and red oak (*Quercus rubra*). Special care in gluing red oak was needed to get shear strengths equal to solid wood values. However, the strength comparisons between sawing methods showed no differences between gang edging and straight-line ripping regardless of gluing procedures.

ODC 836.1

Keywords: Furniture, panels, rough mills, lumber processing

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**Northeastern Forest
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Research Paper
NE-589

1986

Age and Stem Origin of Appalachian Hardwood Reproduction Following A Clearcut and Herbicide Treatment

G. R. Trimble, Jr., E. H. Tryon,
H. Clay Smith, J. D. Hillier

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Abstract

Seven years after a clearcut and herbicide treatment in a West Virginia stand of Appalachian hardwoods, root and stem ages were determined for sugar maple, black cherry, and white ash. Age was used to verify origin and origin was used to evaluate reproduction stem development 7 years after clearcutting. Sugar maple stems originated from advanced reproduction; black cherry originated primarily from seedlings that germinated during or after treatment; and white ash stems were a mixture of seedlings, advanced reproduction, and stump sprouts.

Introduction

This paper is based on a reproduction study of hardwood stem development 7 years after clearcutting. It provides insight into the influence of origin or crown class for three valuable hardwood species. The results have implications that apply to areas of similar site and stand characteristics and silvicultural treatment.

The main objective of this study was to identify reproduction origin class and relate it to total stem height and groundline diameter (primarily for trees in the dominant-codominant crown class) 7 years after clearcutting. A second objective was to use root and stem shoot ages to verify when the reproduction was established. Intermediate and overtopped trees were also evaluated. The hardwood species studied were sugar maple (*Acer saccharum* Marsh.), black cherry (*Prunus serotina* Ehrh.), and white ash (*Fraxinus americana* L.). Reproduction originated from seed, stump sprouts, and advance reproduction. Advanced reproduction was further divided into four classes: seedlings, seedling-sprouts (new), seedling-sprouts (old), and advanced stems.

A number of studies have dealt with the origin of hardwood reproduction after clearcutting (Sander and Clark 1971; McGee and Hooper 1970; McQuilken 1975). Many variables, such as site quality, species composition, and density of the stand before harvesting, affect the reproduction characteristics of the new stand of trees. The study reported here should provide a better understanding of some of these factors and additional information for developing methods to improve species composition. With certain desired species, it is necessary to have advanced reproduction established before harvesting. In other instances, desired species are established after a harvest cut from seed accumulated in the soil.

Study Area

The study area is on the Fernow Experimental Forest near Parsons, West Virginia, maintained by the U.S. Forest Service, Northeastern Forest Experiment Station. The present forest type is mixed Appalachian hardwoods with a site index for red oak of 74 feet at 50 years.

Stand History

The forest was first logged about 1910. It was high-graded, a common logging practice during that period, and many unwanted trees were left. The next disturbance to the forest was the removal in the 1940's of dead stems of American chestnut (*Castanea dentata* (Marsh.) Borkh.) killed during the 1930's by the chestnut blight (*Endothia parasitica*).

Partial cuttings were made in 1958, 1963, and 1968. These light cuttings removed 14, 9, and 6 percent, respectively, of the basal area in trees 5.0 inches or more in d.b.h. The stand was then clearcut between July 1969 and May 1970, and all stems 1.0 to 4.9 inches d.b.h. were sprayed at the base with 2, 4, 5-T. Because small stems were treated with herbicide rather than cut, some potential stems of stump sprout origin were eliminated from the future stand. Trees larger than 5.0 inches d.b.h. were cut. After the removal of sawlogs and pulpwood, only a few living trees between 1.0 and 4.9 inches d.b.h. escaped the herbicide and remained in the stand. Most of the advanced reproduction remaining was less than 1.0 inch in d.b.h.

Stand Description

At the time of clearcutting, the main stand was about 60 years old and had a volume of 7,928 board feet per acre (International ¼-inch rule) in trees over 11.0 inches d.b.h. The basal area was 95 square feet in trees over 5.0 inches d.b.h. Before cutting, trees over 5.0 inches d.b.h. totaled 152 per acre and were mainly chestnut oak (*Quercus prinus* L.), red maple (*Acer rubrum* L.), northern red oak (*Quercus rubra* L.), sweet birch (*Betula lenta* L.), and Fraser magnolia (*Magnolia fraseri* Walt.). Also, some sugar maple and black cherry and a few white ash were present.

The large advance reproduction, stems 1.0 to 4.9 inches d.b.h., totaled 475 stems per acre before cutting and was dominated by American beech (*Fagus grandifolia* Ehrh.) with 145 stems per acre, followed by downy serviceberry (*Amelanchier arborea* (Michx F.)) and sugar maple, each averaging 70 stems per acre. White ash and black cherry were minor components of the large reproduction (about 5 trees per acre). Small advance reproduction, 1.0 foot in height to 0.9 inch in d.b.h., totaled about 3,200 stems and was dominated by sugar maple (710 stems per acre), American beech (400), red maple (330), and sassafras (*Sassafras albidum* (Nutt.) Nees.) (265 stems per acre). White ash and black cherry small advanced reproduction averaged about 100 stems per acre.

During the 7th year after clearcutting, a reproduction inventory found more than 4,000 overstory sapling stems per acre (Fig. 1). Black cherry, yellow-poplar, sugar maple, staghorn sumac (*Rhus typhina* L.), white ash, and black locust (*Robinia pseudoacacia* L.) were the most common overstory species.

Study Methods

Seven years after treatment, approximately 50 dominant-codominant sugar maple, black cherry, and white ash trees were selected at random for study. For the intermediate-overtopped crown class, more than 30 stems were sampled per species, except for black cherry, of which few stems were present. All sample trees were at least 4.5 feet tall. The general overstory stand canopy ranged from 12 to 20 feet high. Study trees were selected with compass line transects randomly established throughout the study area.

Figure 1*A*. Study area after clearcutting. *B*. Seven years later the overstory stems averaged more than 4,000 per acre.

Field Procedure. Species and crown class were recorded for each randomly selected sample stem. The roots of each sample tree (except stump sprouts) were exposed to a depth of about 6 inches below the root collar. Roots were then cut off, leaving 3 to 4 inches of root attached to the stem. Total height of the stem shoot was measured from the root collar to the tip of the terminal leader.

A different method was used in collecting stump sprouts. Sprouts from stumps greater than 2.0 inches in diameter at the groundline were cut off at the union with the stump. Diameter of the stump at the groundline (inches) and height of origin of the sprout on the stump (feet) were recorded. Where there were multiple sprouts, the tallest sprout was sampled. Sprout height was measured from the union of the sprout and stump to the tip of the terminal leader.

Laboratory Procedure. In the laboratory, the age of the stems and roots was determined by sectioning and detailed stem analysis, including X-ray radiography where annual rings were difficult to determine (Renton et al. 1974).

Three stem-origin classes were recognized:

1. New seedlings—stems originating from seed during or after clearcutting.
2. Stump sprouts—sprouts occurring after clearcutting from stumps greater than 2.0 inches in diameter at groundline or from advance reproduction greater than 2.0 inches in diameter at groundline.
3. Advanced reproduction—stems that existed before clearcutting.
   - 3a. Advanced seedlings—root and stem same age and both older than 7 years.
   - 3b. Advanced seedling-sprout (new)—root older than 7 years, stem 7 years or younger.
   - 3c. Advanced seedling-sprout (old)—root older than stem, both root and stem older than 7 years.
   - 3d. Advanced stems—stem older than 7 years, age of root could not be determined.

Analyses. The number of stems in each of the three origin classes was determined for each species by crown class. Where possible, samples from different origin classes within each individual species were tested for significant differences at the 5 percent level. Differences in 7-year total height and groundline stem diameter among the origin classes, other than stump sprouts, were tested for statistical significance by a one-way analysis of variance. Only stems in the dominant-codominant crown class were used for these 7-year growth comparisons, as these taller stems were considered to have grown freely throughout the 7-year period.

Ten different forms of simple regression equations were used to determine whether there were significant relationships between 7-year total height of advance reproduction and groundline diameter at the time of clearcutting. Sometimes data from all available crown classes were used for the regression analyses, and in some cases, the samples were so small that the analyses provided information trends only. Also, the data on seedlings of stump sprout origin were biased by the herbiciding of saplings during the initial treatment.

Results
Root and Shoot Age Relationships—The basis of stem origin

The root and shoot ages were determined for advanced seedlings and seedling-sprouts. Roots from stump sprouts were not aged. Root and shoot ages for dominant-codominant sugar maple were as follows:

9 advanced seedlings—root-shoots averaged 20 years, ranging from 9 to 37 years;

6 advanced seedling-sprouts (new)—roots averaged 19.5 years, ranging from 9 to 42 years; shoots were 7 years old or younger;

14 advanced seedling-sprouts (old)—roots averaged 24 years, ranging from 15 to 43 years; shoots averaged 16 years, ranging from 8 to 26 years (Table 1).

Root and shoot ages for dominant-codominant white ash were as follows:

5 advanced seedlings—root-shoots averaged 12 years, ranging from 9 to 16 years;

3 advanced seedling-sprouts (new)—roots averaged 13 years, ranging from 11 to 15 years, shoots 7 years or younger;

9 advanced seedling-sprouts (old)—roots averaged 21.5 years, ranging from 11 to 44 years, shoots averaged 16.5 years, ranging from 9 to 25 years (Table 1).

For black cherry, the average age of both roots and shoots of advanced seedlings was less than that for sugar maple and white ash. Root and shoot ages for dominant-codominant black cherry were as follows:

3 advanced seedlings—root-shoots were 11.5 years ranging from 10 to 13 years.

6 advanced seedling-sprouts (new)—roots were 12.5 years ranging from 8 to 17 years, shoots were 7 years or younger (Table 1).

Table 1.–Number of stems per root-stem age class for advanced reproduction.

Species	Crown class	Advanced seedlings Age <10	10-19	20-29	30+	Ave.	Advanced seed-sprt (new) Age <10	10-19	20-29	30+	Ave.	Advanced seed-sprt (old) Age <10 R[a]	<10 S	10-19 R	10-19 S	20-29 R	20-29 S	30+ R	30+ S	Ave. R	Ave. S
Sugar maple	D-C[b]	1	5	1	2	20.3	1	3	1	1	19.5	0	3	2	7	11	4	1	0	23.9	16.2
	I-O	0	4	1	0	17.8	1	3	2	1	19.1	0	1	11	12	7	5	0	0	21.3	16.4
Black cherry	D-C	0	3	0	0	11.7	2	4	0	0	12.3	0	0	1	2	1	0	0	0	21.3	16.4
	I-O	1	1	0	0	9.0	0	1	0	0	12.0										
White ash	D-C	2	3	0	0	12.0	0	3	0	0	13.3	0	2	5	4	2	3	2	0	21.7	16.3
	I-O	0	1	0	0	11.0	1	1	0	0	11.5										

[a]R = Root; S = Stem
[b]D-C = Dominant-codominant crown class
I-O = Intermediate-overtopped crown class

Table 2.—Seven-year total heights and groundline diameter[a] by species, origin class, and crown class.

Species	New seedlings No. stems	7-Yr Ht.	7-Yr Dia.	Adv. seed. No. stems	7-Yr Ht.	7-Yr Dia.	Advanced seedling-sprout (New) No. stems	7-Yr Ht.	7-Yr Dia.	Advanced seedling-sprout (Old) No. stems	7-Yr Ht.	7-Yr Dia.	Adv. stems No. stems	7-Yr Ht.	7-Yr Dia.	Stump sprouts No. stems	7-Yr Ht.	7-Yr Dia.
		ft	*in*		*ft*	*in*		*ft*	*in*		*ft*	*in*		*ft*	*in*		*ft*	*in*
DOMINANT-CODOMINANT CROWN CLASS																		
Sugar maple	—	—	—	9	14.5	1.3	6	12.4	1.7	14	13.9	2.0	15	16.2	2.4	5	14.6	1.9
Black cherry	36	14.9	1.3	3	22.0	2.7	6	17.8	1.7	2	20.0	2.0	—	—	—	1	20.7	3.0
White ash	23	12.4	1.4	5	16.0	1.9	3	13.3	2.0	9	15.2	1.6	2	20.0	3.8	9	17.1	1.8
INTERMEDIATE-OVERTOPPED CROWN CLASS																		
Sugar maple	—	—	—	5	8.7	0.8	7	8.9	0.7	18	9.3	0.8	1	14.2	1.0	2	10.6	1.2
Black cherry	9	12.3	0.8	2	12.2	0.7	1	14.3	1.0	—	—	—	—	—	—	—	—	—
White ash	33	7.8	0.6	1	8.9	0.8	2	12.6	0.9	—	—	—	—	—	—	—	—	—

[a]Groundline stem or stump sprout diameter.

Predicting total height using groundline stem diameter

Only two advanced seedling-sprouts (old) of black cherry were measured and the roots were 13 and 21 years old, while the shoot ages were 10 and 18, respectively. Though a few black cherry roots and shoots of advanced reproduction were 15 years plus, most of the roots were about 10 years old, indicating that the more intolerant black cherry do not normally live as long as the sugar maple or white ash in the undisturbed stand.

Origin of stems by crown class. A total of 82 sugar maple stems were sampled; of the 49 dominant-codominant stems, 41 percent were advanced seedling-sprouts and 18 percent were advanced seedlings (Table 2). Also, 31 percent of advanced stems could not be categorized as either seedlings or seedling-sprouts because of aging difficulties. No new sugar maple seedlings taller than 4.5 feet were sampled. Since stems less than 5.0 inches d.b.h. had been herbicided, few stump sprouts were found. Sixty-seven percent of the intermediate-overtopped sugar maple stems were advanced seedling-sprouts (Table 2). Advanced seedling-sprouts dominated the sugar maple reproduction origin class in the 7-year-old even-aged stand.

Black cherry and white ash had considerably more new stems of seedling origin than sugar maple. Of the 48 dominant-codominant black cherry stems sampled, 75 percent originated as new seedlings and 17 percent were advanced seedling-sprouts (Table 2). Similarly, of the 12 intermediate-overtopped black cherry stems, 75 percent were new seedlings. A total of 51 dominant-codominant white ash trees were sampled. From this total, 45 percent were designated new seedlings, and 24 percent were advanced seedling-sprouts (Table 2). Also, 36 white ash stems were in the intermediate-overtopped class and 92 percent of these stems were new seedlings.

Effect of stem origin on height and groundline diameter. In general, for white ash and sugar maple, stump sprouts were as tall or taller than advanced seedlings, taller than advanced seedling-sprouts (old), and taller than advanced seedling-sprouts (new). For black cherry, the number of samples was too low for comparisons (Table 2). However, where present, the intolerant black cherry stems within a similar origin class were always taller than the white ash or sugar maple 7 years after clearcutting (Table 2).

After 7 years, dominant-codominant advanced seedling-origin stems had the smallest groundline stem diameter among sugar maple origin classes (Table 2). Groundline diameter for advanced black cherry seedling-sprouts (new and old) averaged about 0.5 inches more than new seedlings. Also, as expected, white ash advanced seedlings and seedling-sprouts were consistently larger in groundline stem diameter than new seedling reproduction.

Groundline stem diameter when the stand was cut was used to predict total height of advanced reproduction 7 years after clearcutting. We cannot recommend using groundline stem diameter to predict 7-year total height for advanced seedlings (excluding seedling sprouts). More data are needed.

For all sugar maple crown classes in the advanced seedling-sprouts (old and new) reproduction stem origin category the best regression, though significant, was low, with an R^2 of 0.41. Similar regressions for black cherry ($R^2 = 0.58$) and white ash ($R^2 = 0.77$) were significant too. Total height-initial groundline diameter regressions for advanced seedling-sprouts (new) from all crown classes improved slightly for sugar maple ($R^2 = 0.50$) and black cherry ($R^2 = 0.87$). All coefficients were significant. Too few data were available to calculate R^2 values for white ash.

In general, for advanced seedling-sprouts, data for black cherry and to a lesser degree white ash indicated that initial groundline stem diameter could be used as a predictor of 7-year total height. Many of the better regression equations were in the form:

$$Y = a \pm b \, (\log X)$$

where Y = Total height (7-year) in feet
X = Groundline stem diameter (initial) in inches
Log = Common log (base 10)

Using the equation for all crown classes of black cherry advanced seedling-sprouts (new),

$$Y = 20.184 + 9.059 \, (\log 0.5)$$
$$Y = 20.184 + 9.059 \, (-0.30)$$
$$Y = 17.5 \text{ feet}$$

thus if the initial groundline stem diameter was 0.5 inches the total height at 7 years would be 17.6 feet and the R^2 would be 0.87.

Data from all advanced stem origin classes were combined for all crown classes and separate equations developed for each species. Results indicate that prediction equations were acceptable for sugar maple ($R^2 = 0.73$) and white ash ($R^2 = 0.63$); however, the equation for black cherry ($R^2 = 0.22$) was poor. Thus, combining advanced seedlings with advanced seedling-sprouts for all crown classes and using the groundline diameter at clearcutting to predict total height 7 years later could be done for sugar maple and white ash stems.

By measuring groundline stem diameter for advanced reproduction when the stand was clearcut, we can make a rea-

sonable prediction of how tall a tree will be in the stand 7 years later. For example, if the groundline stem diameter of an advanced white ash stem was 0.8, the total height after 7 years would be estimated at between 11 and 12 feet (11.6 feet) when using the equation for white ash as indicated:

White ash $Y = 12.84 + 12.30 (\log X)$;
Sugar maple $Y = 10.51 + 14.57 (\log X)$;
Black cherry $Y = 20.91 + 6.12 (\log X)$.

However, we realize more data are needed to develop better equations for the stem origin categories. And once better equations are developed, the predicted values need to be verified with more field data.

Discussion

We recognize that the herbicide treatment had some effect on the availability of stems of stump sprout origin, but we cannot evaluate this effect. More stump-sprout origin stems would be expected from a normal clearcut than from a clearcut with herbicide. However, the root-shoot age for advanced reproduction would not be affected. The age of roots indicated that the small advanced sugar maple reproduction averaged about 20 years, but some roots were more than 40 years old. Tryon and Powell (1984) reported that advanced white ash seedlings were slightly younger than the sugar maples, but some advanced seedling sprouts were also more than 40 years old. Advanced black cherry seedling roots were considerably younger than those of sugar maple and white ash. Black cherry roots averaged about 12 years. In view of the age of advanced reproduction, classical silviculturists may consider revising their thoughts on even-aged and uneven-aged hardwood stands.

In this study, advance reproduction is the most important source of sugar maple stems; 90 percent of the dominant-codominant stems originated from advanced seedling-sprouts or seedlings. The establishment of new seedlings as a result of treatment was the major source of black cherry stems, accounting for 75 percent of the dominant-codominant stems. However, the origin of white ash stems was more evenly distributed: New ash seedlings accounted for 45 percent and advanced reproduction 37 percent of the ash reproduction. Thus, advanced reproduction plays a major role in stem development of sugar maple and white ash, but for black cherry, the development of new seedlings was a significant factor in this study. The recent periodic light thinnings could have influenced the establishment and development of advanced regeneration, too.

The results of this study generally support earlier findings that species behavior is related to shade tolerance, crown class, and growth rates. These variables interact with differences in stand conditions and treatments.

Some meaningful regressions were found using initial groundline stem diameter to predict 7-year total height for advanced stems and advanced seedling-sprouts. However, more data and field verification of the predicted values are needed.

Sugar maple. Sugar maple is the most shade tolerant of the three species studied, and new seedlings failed to produce dominant-codominant trees 7 years after clearcutting. Smith (1983) found that even with annual removal of competing forest vegetation, small sugar maple stems did not maintain enough height growth after clearcutting to compete.

Winget (1968) in Quebec and Ostrom (1938) in Pennsylvania observed that sugar maple developed almost entirely from advance reproduction. Sugar maple is able to withstand several years of complete suppression and still respond to release (Downs 1946). However, small reproduction at the time of clearcutting cannot compete with the surge of faster-growing, more intolerant vegetation. Most of the sugar maple stems in even-aged stands in Pennsylvania were found to be old advance reproduction from sapling or small pole-sized advance reproduction (Marquis et al. 1975).

Black cherry. New black cherry seedlings grew well when released, faster than both sugar maple and white ash. Black cherry is the most shade-intolerant of the three species. Unlike sugar maples, many of the dominant-codominant black cherry stems 7 years after cutting originated from new seedlings. Several reproduction studies following clearcutting on sites similar to this study area indicate that black cherry is a consistent component of the new stands. In no instance were advance stems (1.0 to 4.9 inches d.b.h.) of this species present in any appreciable numbers unless the stands had previously been subjected to partial cuttings.

White ash. Less information is available for white ash than for the other two species, but it is intermediate in tolerance between the more tolerant sugar maple and less tolerant black cherry. White ash is also intermediate in total height growth rate between sugar maple and black cherry. In the seedling stage, white ash is generally tolerant and sprouts well, but it becomes more intolerant with increasing age (Wright 1965; Logan 1973). Logan (1973) also concluded that white ash seedlings grown in 87 percent artificial shade were as tall as those in full light, but the maximum dry weight was produced at 55 percent shade.

White ash seldom occurs in pure stands, and in West Virginia ash is rarely a major component of the stand. For example, in this study 46 percent of the dominant and codominant white ash reproduction came from new seedlings and 37 percent came from advanced reproduction. This suggests that ash could be present following either clearcutting or selection regeneration in these Appalachian mixed hardwood stands. However, as mentioned earlier, white ash is tolerant as a seedling but needs light after the seedling

stage. Therefore, where white ash occurs in the understory and is desired, the shelterwood method seems to be a logical natural regeneration method to increase the white ash component.

Silviculture research provides some information as to why certain species occur in given situations. Sugar maple can be grown under even-age mangement. Single-tree selection is also well suited to sugar maple, and the species can be grown by group selection and diameter-limit cuts, too.

Where black cherry is to be favored, even-age management is preferable because this species is shade intolerant and grows rapidly when young. The abundant seed crops and seeds which lie dormant for 3 to 4 years (Wendel 1977) usually provide for a source of advanced regeneration or new seedlings. The study reported here shows that black cherry seedlings were the main source of the dominant-codominant stems in the 7-year-old even-aged stand. Shelterwood is not needed to establish black cherry in this area, since good periodic seed crops and clearcutting will provide all the black cherry stems needed for the future stand.

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Caution

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key—out of the reach of children and animals—and away from food and feed.

Apply pesticides so they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

NOTE: Some states have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the Environmental Protection Agency, consult your local forest pathologist, county agricultural agent, or State Extension specialist to be sure the intended use is still registered.

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Trimble, G. R., Jr.; Tryon, E. H.; Smith, H. Clay; Hillier, J. D. **Age and stem origin of Appalachian hardwood reproduction following a clearcut-herbicide treatment.** Res. Pap. NE-589. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1986. 8 p.

Seven years after a clearcut-herbicide treatment in a West Virginia Appalachian hardwood stand, root-stem age was determined for sugar maple, black cherry, and white ash. Sugar maple stems originated from advanced reproduction, black cherry originated primarily from seedlings that germinated during or after treatment, and white ash stems were a mixture of seedlings, advanced reproduction, and stump sprouts.

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Headquarters of the Northeastern Forest Experiment Station are in Broomall, Pa. Field laboratories are maintained at:

- Amherst, Massachusetts, in cooperation with the University of Massachusetts.
- Berea, Kentucky, in cooperation with Berea College.
- Burlington, Vermont, in cooperation with the University of Vermont.
- Delaware, Ohio.
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- Parsons, West Virginia.
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**Northeastern Forest
Experiment Station**

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Butt-log Grade Distributions for Five Appalachian Hardwood Species

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Abstract

Tree quality is an important factor in determining the market value of hardwood timber stands, but many forest inventories do not include estimates of tree quality. Butt-log grade distributions were developed for northern red oak, black oak, white oak, chestnut oak, and yellow-poplar using USDA Forest Service log grades on more than 4,700 trees in West Virginia. Butt-log grade distributions indicate the probabilities associated with each grade for each species and d.b.h. class. These estimates are useful for predicting the value of timber stands for which stand tables are available.

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Introduction

Timber cruises usually involve the estimation of board-foot sawtimber volumes, cordwood volumes, and stand growth. One variable that is not commonly measured, but is important in estimating the actual value of a stand, is the stem quality of trees sampled in the cruise. Butt-log grade is a measure of stem quality that can be estimated from empirical equations relating butt-log grade to tree d.b.h. (Ernst and Marquis 1979). We developed equations and butt-log grade distributions for five Appalachian hardwood species. The distributions are useful for estimating average tree quality and stand value when stem quality data are not available.

Methods

Empirical grade equations were derived from Forest Survey point samples containing information on species, d.b.h. (D), and butt-log grade. The species included northern red oak, black oak, white oak, chestnut oak, and yellow-poplar. Data were from 4,781 sawtimber trees ranging from 10 to 25 inches d.b.h. on point samples placed throughout West Virginia.[1] USDA Forest Service log grades (Rast and others 1973) were used to grade the butt 16-foot log of each sample tree.

Three regression equations were developed for each species. The equations related the inverse of tree d.b.h. (D^{-1}) to:

(1) The proportion of sawtimber trees with a grade 1 butt log;

(2) The proportion of sawtimber trees with a grade 3 butt log;

(3) The proportion of sawtimber trees with a butt log below grade 3.

All regressions were weighted by the actual number of sawtimber trees in a diameter class times $1/D^2$, because trees were selected by point sampling. Analyses of covariance indicated that the following combinations of oak species were acceptable: red and black oak, and white and chestnut oak.

[1]Data were provided by the Forest Inventory and Analysis Research unit of the USDA Forest Service, Northeastern Forest Experiment Station, for the State of West Virginia.

Results

Butt-log grade distributions for yellow-poplar, red and black oak, and white and chestnut oak are presented in Tables 1-3. The grade distributions were predicted from the regression equations presented in Table 4. Coefficients of determination (R^2) ranged from 0.49 to 0.90. For each grade distribution, the percentage of sawtimber trees with butt logs in grade 1, 3, or "below grade" were predicted from the equations. The percentage of trees with grade 2 butt logs was found by subtraction.

For each species group and diameter class, the percentage of sawtimber trees with below-grade butt logs was computed first. Below-grade logs are not used to produce factory grade lumber. They include construction logs used for ties and timbers and local-use logs (Rast and others 1973). The predicted percentage of trees with below-grade butt logs decreased as d.b.h. increased in each species group (Tables 1-3).

From 10 to 11 inches d.b.h., the percentage of trees with grade 3 butt logs was determined by subtraction. In these diameter classes, grade 3 is the best possible grade due to size limits in the grading rules (Rast and others 1973). From 13 to 14 inches d.b.h., the percentage of trees with grade 3 butt logs was computed from the equations, and the percentage with grade 2 butt logs was determined by subtraction. In these diameter classes, the butt logs are too small to be grade 1. For trees 15 inches d.b.h. and larger, the percentage of trees with butt-log grades 1 and 3 were computed from the equations, and the percentage with butt-log grade 2 was determined by subtraction. Thus, the percentage of trees in each grade category for a particular diameter class totals 100.

Making Value Determinations

Forest Service tree grades (Hanks 1976) are useful for predicting lumber grade yields and the market value of individual sawtimber trees. Although tree grades and butt-log grades differ with respect to scaling diameter and allowable cull, surface requirements are the same in both grading systems. With some minor changes, the butt-log grade distributions presented here can be transposed to tree grades for estimating stumpage values.

The minimum diameters for *tree* grades 1, 2, and 3 are 10, 13, and 16 inches d.b.h., respectively (Hanks 1976). To approximate tree grade distributions from those presented in Tables 1-3, assume that no 12-inch trees are grade 2 and that no 15-inch trees are grade 1. This will increase the percentage of 12-inch trees that are grade 3 and the percentage of 15-inch trees that are grade 2. The total distribution in each diameter class equals 100 percent.

Table 1.—Butt-log grade distributions for yellow-poplar

D.b.h. (inches)	No. of trees	Grade 1	Grade 2	Grade 3	Below grade
		Percent			
10	123	—	—	74	26
11	99	—	—	78	22
12	112	—	9	71	20
13	123	—	24	59	17
14	108	—	37	48	15
15	85	29	19	39	13
16	82	36	20	32	12
17	73	41	23	25	11
18	46	47	25	19	9
19	28	51	28	13	8
20	34	56	29	8	7
21	23	59	31	4	6
22	18	63	30	1	6
23	7	66	29	1	5
24	6	69	26	1	4
25	9	72	23	1	4
Total	976				

Table 2.—Butt-log grade distributions for red and black oak

D.b.h. (inches)	No. of trees	Grade 1	Grade 2	Grade 3	Below grade
		Percent			
10	161	—	—	81	19
11	144	—	—	83	17
12	141	—	11	74	15
13	130	—	23	64	13
14	164	—	34	54	12
15	126	19	25	46	10
16	133	25	27	39	9
17	110	30	29	33	8
18	105	35	30	27	8
19	87	39	32	22	7
20	79	43	33	18	6
21	63	46	34	14	6
22	58	49	36	10	5
23	40	52	36	7	5
24	42	54	38	4	4
25	31	57	38	1	4
Total	1,614				

Table 3.—Butt-log grade distributions for white and chestnut oak

D.b.h. (inches)	No. of trees	Grade 1	Grade 2	Grade 3	Below grade
			Percent		
10	264	—	—	76	24
11	255	—	—	79	21
12	233	—	5	76	19
13	208	—	15	68	17
14	229	—	23	61	16
15	196	6	25	55	14
16	142	10	27	50	13
17	126	14	29	45	12
18	105	17	31	41	11
19	94	20	32	38	10
20	99	23	34	34	9
21	65	25	36	31	8
22	54	27	36	29	8
23	34	29	38	26	7
24	37	31	38	24	7
25	23	33	39	22	6
Total	2,164				

Table 4.—Regression statistics for dependent variable of percentage of trees in given grades

Species	Grade 1		Grade 3		Construction	
	Equation[a]	R^2	Equation[a]	R^2	Equation[a]	R^2
Yellow-poplar	$Y = 135.6 - 1601.4\ D^{1}$	.62	$Y = -86.2 + 1885.5\ D^{1}$	.90	$Y = -11.0 + 365.9\ D^{1}$	.79
Red, black oaks	$Y = 112.7 - 1403.1\ D^{1}$	.73	$Y = -67.4 + 1702.2\ D^{1}$	.89	$Y = -6.4 + 252.6\ D^{1}$	.49
White, chestnut oaks	$Y = 73.8 - 1021.4\ D^{1}$	.61	$Y = -27.8 + 1241.0\ D^{1}$	.83	$Y = -6.0 + 302.3\ D^{1}$	.62

[a] Y = Percentage of trees by grade; D^1 = 1/d.b.h. (percentage of trees with grade 2 butt logs is found by subtraction.)

The adjusted grade distributions indicate how many trees in each diameter class are grade 1, 2, 3, or below grade for each species group. For example, a stand table reveals that a 50-acre stand contains 126 northern red oaks in the 18-inch diameter class. The grade distribution for the red oak-black oak group (Table 2) estimates the number of trees in each grade (Table 5). This procedure is repeated for each diameter class and for each species until all trees have been "graded."

Table 5.—Tree grade distribution of 126 northern red oaks on a 50-acre forest tract

Tree grade	Probability	Estimated no. of trees in each grade
1	0.35	44
2	0.30	38
3	0.27	34
4	0.08	10

The final step is estimating the market value of individual trees in each species group. Table 6 lists the average lumber yields and current lumber prices for a northern red oak, 18 inches d.b.h., with a grade 1 butt log and a merchantable height of 32 feet. The sum of current lumber prices (Lemsky 1985) applied to each lumber grade yield is the total value of lumber in the tree, $100.05. The value of lumber in a similar tree with a grade 2 butt log is $85.74. With a grade 3 butt log, the value drops to $65.32. The value of products in trees below grade 3 depends on local-use markets. For this example, we assumed the value of products in trees below grade was $40.

Table 6.—Value of lumber in a northern red oak, 18 inches d.b.h., with a grade 1 butt log and merchantable height of 32 feet

Lumber grade	Volume[a]	Lumber price[b] per M bf	Lumber value
	Board feet	*Dollars*	
FAS	35.9	$715	$ 25.67
1F	26.0	705	18.33
No. 1C	66.1	525	34.70
No. 2C	65.5	207	13.56
No. 3A	44.0	177	7.79
Total	237.5		100.05

[a] From Hanks 1976.
[b] From Lemsky 1985.

Stumpage prices can be obtained by subtracting conversion costs and a margin for profit and risk. In this example, the lumber grade yields (Hanks 1976) and current lumber prices (Lemsky 1985) for 126 northern red oaks resulted in an average lumber value of $361 per thousand board feet (M bf). If conversion costs and a margin for profit and risk equal $220 per M bf, the stumpage price for 18-inch red oaks is $141 per M bf. This could be expanded to include trees in all d.b.h. classes for red oak and result in one average stumpage price for the species. As lumber prices and conversion costs change, individual-tree values and average stumpage prices can be adjusted accordingly.

Discussion

Butt-log grade distributions can be used to estimate individual-tree and stand values when actual grade data are not available. Regression equations or grade distribution tables predict the percentage of trees in each grade for a particular species and diameter class. This information provides a basis for estimating lumber grade yields, total lumber value, and the residual stumpage value for any number of sawtimber trees. The user should first develop a stand table that indicates the number of trees by species and d.b.h., and an estimate of average merchantable height.

The regression equations can be used to incorporate grade distributions into stand value computer programs. An important advantage of using butt-log grades when estimating stand value is that dollar values include the effect of timber quality and current lumber prices. In cases involving timber trespass, for example, the grade distributions can be used to estimate the total value of losses based on the probable grade of the trees cut. Similarly, the distributions provide a basis for computing potential stand value from projections of individual-tree diameter growth and the accompanying changes in grade. In both examples, the value estimates include the effect of stem quality as well as species, tree size, and total volume.

Because butt-log grade data for this study were collected in unmanaged, central Appalachian hardwood stands throughout West Virginia, the distributions may have limited use outside the general study area. In addition, intensive timber management practices may result in grade distributions significantly different from those presented here. The user should be aware that such differences may occur and that additional grade distributions may be needed for some stands.

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Tree quality is an important factor in determining the market value of hardwood timber stands, but many forest inventories do not include estimates of tree quality. Butt-log grade distributions were developed for northern red oak, black oak, white oak, chestnut oak, and yellow-poplar using USDA Forest Service log grades on more than 4,700 trees in West Virginia. Butt-log grade distributions indicate the probabilities associated with each grade for each species and d.b.h. class. These estimates are useful for predicting the value of timber stands for which stand tables are available.

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Growth and Nutrient Status of Black Spruce Seedlings As Affected by Water Table Depth

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Abstract

A greenhouse experiment was conducted to study the effects of soil water level on growth, biomass accretion, and inorganic element uptake by black spruce. One-year-old containerized seedlings were grown for 3 years at three water table depths. All trees survived for the duration of the study confirming that black spruce has a certain degree of survival tolerance to high water tables. However, tree height, diameter growth, and biomass production significantly increased as the depth to water table increased.

The foliar levels of N, P, K, Mg, Fe, Zn, and B increased and those of Cu and Mn decreased with the increasing depth to the water table. For ash and Ca, differences were significant but did not follow a consistent trend. In shoots, the level of N, Ca, and Mg increased and those of ash, K, Fe, Cu, B, Al, and Mn decreased with the increasing depth to the water table. The level of P was not affected by the water table. In roots, the level of N and Ca increased and the level of ash, Mn, Fe, Al, and Cu decreased with increasing depth to the water table. The level of P, Mg, and Zn was significantly different but did not follow any trend.

Foliar concentration of ash, Ca, Na, Mn, Fe, Zn, Cu, Al, and B increased and concentration of N, P, K, and Mg decreased with the increasing foliage age. In shoots, ash, Ca, Al, Fe, and Zn increased and N, P, K, Mg, and B decreased with the increasing tree and shoot age. In roots, Fe, Mn, Na, and Al increased and N, P, and Cu decreased with the increasing tree age.

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Introduction

Black spruce (*Picea mariana* (Mill) B.S.P.) is an important component of the spruce-fir forest of northern Maine. It occupies about 6 to 7 percent of spruce-fir forest area. The species occurs naturally on a variety of soil and site conditions, but most frequently it is associated with swamps, extensive flatlands, and fringes of lakes where seomewhat poorly drained to very poorly drained soils occur. Many sites are occasionally flooded for prolonged periods, but the species seems to be morphologically adapted to survive periodic inundation.

Since black spruce is the least susceptible of all spruces to spruce budworm (*Choristoneura fumiferana* Clem.) infestations, it has become a favored species for reforestation programs. Extensive plantations are being established on sites that vary in soil drainage conditions, and containerized seedlings are most commonly used as planting stock. Since soil drainage is of utmost importance to forest growth, the establishment of physiologically healthy plantations on poorly drained soil may be a problem. The soil conditions and the stresses likely to affect plant growth from excessive soil moisture have been well discussed in many publications. They were reviewed by Cannell and Jackson (1981).

Examples of adverse effects on height and diameter growth of southern pine seedlings resulting from high water tables were presented by Burton (1971), McKee and Shoulders (1974), McKee and others (1984), and Mueller-Dombois (1964). Little has been written concerning the effects of excessive moisture or of soil drainage on black spruce. Czapowskyj (1982) reported that mechanical drainage of very poorly drained soils in northern Maine resulted in a positive response by young natural black spruce. Thus, there is a need to evaluate the influence of the soil water table level on black spruce growth and nutrient uptake during initial stages of plantation establishment given the growing interest in artificial regeneration using this species.

The objective of this study was to determine the effect of different soil water table levels on growth, biomass production, and nutrient accumulation in black spruce seedlings growing under greenhouse conditions over three growing seasons after transplanting.

Study

Black spruce seedlings were planted in plastic pots in the spring of 1981 and were grown in the greenhouse with three water table regimens for three growing seasons.

Seedlings

One-year-old container grown seedlings were obtained in May 1981 from the Great Northern Paper Company overwintering beds in Millinocket, Maine. The seedlings were raised from seeds obtained from J. D. Irving, Ltd., Juniper, New Brunswick—Lot No. SB 58 Restigouche Region—and were grown in a peat moss-vermiculite mix in Japanese paper pots (FH-408) starting in May 1980 for 12 weeks in a greenhouse. During this period, the seedlings were fertilized 6 times at 6- to 10-day intervals using commercial fertilizer formulations, 4 times with 20-20-20 followed by two applications of 9-45-15, at a rate of about 12 grams per 1,000 seedlings plus one application of micronutrients (0.5 gm/1,000 seedlings). In August 1980, the seedlings were transferred from the greenhouse and placed in outside beds to harden off and overwinter. During April and May of 1981, the seedlings received additional fertilizer treatments; five applications of 9-45-15 plus five applications of micronutrients at the same rates as the previous year. Mensurational data and nutrient concentrations of the seedlings at the beginning of this study are given in Table 1.

Growth Medium

The seedlings were planted in soil collected from the spodic horizon from the Telos soil series (coarse-loamy, mixed, frigid, Aquic Haplorthods). This soil is somewhat poorly drained and occurs in extensive, contiguous blocks in the spruce-fir region of northern Maine. It is associated with the moderately well drained Chesuncook and the poorly drained Monarda soils. The Telos soil occurs in gently sloping areas and has slow or very slow permeability in the substratum because of its dense, low-porosity nature. The upper soil layers above the dense basal till are moderately permeable and of lower density. The soils are extremely to very strongly acid (pH 4.2 to 5.0). The combination of little relief and slow permeability result in a high water table in the spring and fall and in periods of high rainfall during the growing season. Soil was transported to the greenhouse, air dried, and sieved through a sieve with 1.3-cm openings.

Study Layout

Sixty plastic pots, 30 cm in height with a surface area of 6.5 dm^2, were filled with approximately 20 kg of soil. Each pot was planted with three seedlings, for a total of 180 seedlings. A 3-cm layer of peat moss was placed on the soil surface in each pot to simulate the organic layer usually found on forest sites. The pots were then placed in a 1.25-m $\times$ 2.50-m water tank with a fixed overflow elevation to simulate three water table levels. The polyethylene-lined plywood tank was constructed in such a way that each water table regime contained 20 pots. The water table levels were 4, 10, and 20 cm below the mineral soil surface—WT 4, WT 10, and WT 20, respectively.

Water was automatically pumped from an overflow reservoir into the tank at timed intervals in order to replace losses due to evaporation. At the initiation of the study, the pH of the

Table 1.—Physical characteristics and concentration of nutrient elements in 1-year-old containerized seedlings prior to planting[1]

Seedling characteristic and nutrient element	Foliage	Shoot	Root	Total seedling
Height, cm	—	13.4	—	—
RCD,[2] mm	—	2.0	—	—
Oven-dry weight, g	0.29	.11	0.19	0.59
Nitrogen, percent	1.43	.85	.54	1.04
Phosphorus, percent	.27	.12	.29	.25
Potassium, percent	1.08	.86	.74	.78
Calcium, percent	.87	.35	.79	.76
Magnesium, percent	.13	.12	.39	.22
Manganese, mg/kg	200	100	100	183
Iron, mg/kg	181	174	2056	745
Zinc, mg/kg	124	125	366	205
Copper, mg/kg	16	60	42	32
Boron, mg/kg	31	20	76	44
Aluminum, mg/kg	100	100	200	133
Ash, percent	4.44	2.76	7.60	5.21

[1]Based on a sample of 25 seedlings.
[2]Root collar diameter.

water in the tank was adjusted to match the typical pH of forest soil solution.

At the end of October in each growing season, the pots were drained and placed in an outside unheated trailer for overwintering. At mid-April of the second and third growing seasons they were transferred to the greenhouse and arranged in the same order and placed under the same water table regime as they were during the first growing season.

Growth Analyses

Survival counts, height, and diameter (at ground line) were measured at 2-week intervals from the beginning of May to mid-October during each growing season. Each year at the end of October one seedling was harvested from each pot for growth and biomass measurements as well as to determine nutrient concentrations of foliage, shoots, and roots. Roots were separated and washed in distilled water, foliage was separated from the shoots, and the components were dried at 65°C to constant weight. Because the trees were small, three composite samples were prepared from 20 trees in each treatment. Samples were ground to pass a 20-mesh screen and stored for chemical analyses.

Chemical Analyses

The samples were dry-ashed at 480°C, and ash content was determined gravimetrically. The ash was taken up in dilute HCL, and phosphorus (P), calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), manganese (Mn), zinc (Zn), iron (Fe), aluminum (Al), and boron (B) were determined by inductively coupled plasma emission spectroscopy (ICP) at the Universeity of Maine. Nitrogen (N) was determined from Kjeldahl digestions by an autoanalyzer. All analyses were performed in duplicate on the oven-dry (65°C) samples.

Data Analysis

The data were tabulated by seedling age, component age, and by the depth to water level. Tree growth attributes (height, diameter, and oven-dry weight), percentage of ash, and nutrient concentrations were analyzed statistically by analysis of variance. Duncan's new multiple range test was used for mean separations.

Results and Discussions

Survival

Seedling survival was not affected by the depth to the water table. All trees remained alive for the duration of the study, indicating the ability of black spruce to survive under high water table levels.

Buds started to break 1 week after the pots were returned from the overwintering environment to the greenhouse. Buds broke first on trees with treatment WT-20. The WT-4 and

WT-10 treatments had bud break delayed for 6 to 8 days. Delayed bud break on trees subjected to waterlogging is a common phenomenon that has been observed in the past (Coutts 1981). In addition, the foliage of trees with WT-4 and WT-10 regimens was consistently chlorotic, as is typical of saturated soil conditions.

Height and Diameter Growth

Biweekly measurements taken during the growing season revealed that shoots grew for about 8 weeks regardless of the water table regime. However, the diameter growth of seedlings in the WT-4 regime ceased after 12 weeks, but continued in the WT-10 and WT-20 regimes for a total of 20 weeks.

Average annual height and diameter growth (Table 2) show tree response to differences in water table levels. These responses were significant ($p = 0.05$) and both the mean height and mean diameter were ordered as follows: WT-4 $\bar{x}$ < WT-10 $\bar{x}$ < WT-20 $\bar{x}$. This pattern held for the entire study period.

Table 2.—Mean height and diameter at root collar of black spruce as affected by depth to water table and growing season

Tree characteristic	WT-4	WT-10	WT-20
	Tree Age, 1 + 1—60 trees sampled		
Height, cm	18.2b[2]	19.9a	20.2a
RCD,[1] mm	2.9c	3.2b	3.5a
	Tree age, 1 + 2—40 trees sampled		
Height, cm	26.4c	30.2b	35.7a
RCD, mm	4.0c	5.0b	6.2a
	Tree age, 1 + 3—20 trees sampled		
Height, cm	29.6c	34.0b	41.9a
RCD, mm	5.1c	6.5b	8.5a

[1]Root collar diameter.
[2]Lower case letters designate differences between water table levels of the same year at the 0.05 level, using Duncan's New Multiple Range Test.

Biomass Allocation

Data presented in Table 3 show the means and differences in biomass allocation by tree component for the three water table regimens. For each of the 3 years, biomass responded to water table regimes similarly to tree height and diameter. The differences were significant for all years and the means were ordered as follows: WT-4 < WT-10 < WT-20. By expressing the data in Table 3 in relative terms (percent), the experiment wise (years x water level) allocation of extra biomass attributable to better drainage was ordered as follows: foliage > shoots > roots. The differences in root:shoot ratios were negligible: 37;38;41 percent for WT-4, WT-10, and WT-20, respectively, at the conclusion of the study.

All three growth measurements (height, diameter, and biomass) provide additional evidence that the high water table had a negative effect on the performance of black spruce. Trees that were grown under the high water tables (WT-4 and WT-10) showed signs of stress from poor aeration resulting in reduced oxygen diffusion. The stress symptoms—reduced growth, chlorosis, abscission of the foliage, and deformation of root systems—were consistent with those reported by Norby and Kozlowski (1983) for other species.

Further examination of the data given in Table 2 and 3 and Figure 1 shows that lowering the water level by 6 cm (from 4 to 10 cm) resulted in height increases of 15 percent, diameter increases of 27 percent, and total biomass increases of 68 percent. Height increased by 42 percent, diameter increased by 67 percent, and biomass nearly doubled when the water table was lowered to 20 cm.

Concentrations and Distribution of Ash and Mineral Elements

The effects of both water level and seedling age on concentrations of ash, and selected elements in the foliage, shoots, and roots are readily apparent in Table 4. Because of a lack of trends and the small magnitudes in differences, the values for ash and Al concentrations were presented as averages of all three water table levels (Table 4). A summary of analysis of variance showing significant differences is presented in Table 5. Changes in nutrient composition varied considerably among individual components, water table levels, and component age classes.

Needles. Mean concentrations of N, P, K, Mg, Fe, B, and Zn increased and those of Mn and Cu decreased with increasing depth to water table. For ash and Ca, the differences in concentration were significant but did not follow a consistent trend. Concentrations of Al did not differ between water levels.

Concentrations of ash and all mineral elements varied greatly with foliage age. The overall mean concentrations of ash, Ca, Na, Al, Zn, Fe, Cu, and B increased and those of N, P, K, and Mg decreased with an increasing foliage age from current-year to 2- and 3-year-old needles. Inconsistencies were observed in Mg concentrations, but the differences were small (Table 4).

Shoots. Mean concentrations of N, Ca, and Mg increased and those of ash, K, Fe, Cu, B, Mn, and Al decreased along the gradient of increasing depth to water table level. No

Table 3.—Mean component weight of black spruce seedlings raised under three depths of water table for a period of 3 years (average of 20 trees sampled)

Biomass	WT-4		WT-10		WT-20	
	g	*percent*	*g*	*percent*	*g*	*percent*
			Tree Age, 1 + 1			
Foliage	0.8c[1]	42	1.1b	44	1.4a	45
Shoots	.6c	32	.8b	32	1.0a	32
Roots	.5b	26	.6b	24	.7a	23
Total	1.9c	100	2.5b	100	3.1a	100
Root: Shoot Ratio	.29		.32		.38	
$^{m}1000$[2]	.68		.80		.78	
			Tree Age, 1 + 2			
Foliage	2.8c	43	3.8b	43	6.9a	40
Shoots	2.0b	30	2.6b	29	5.7a	32
Roots	1.8b	27	2.5b	28	4.8a	28
Total	6.6c	100	8.9b	100	17.4a	100
Root: Shoot Ratio	.38		.39		.37	
$^{m}1000$	.69		.65		.74	
			Tree Age, 1 + 3			
Foliage	4.8c	41	8.2b	42	13.1a	38
Shoots	3.5c	30	6.0b	31	11.8a	35
Roots	3.4c	29	5.4b	27	9.2a	27
Total	11.7c	100	19.6b	100	34.1a	100
Root: Shoot Ratio	.37		.38		.41	
$^{m}1000$	.69		.74		.69	

[1]Lower case letters designate differences between water table levels of the same year at the 0.05 level, using Duncan's New Multiple Range Test.
[2]1,000 needles weight.

Table 4.—Mean concentrations of ash and nutrient elements in black spruce as related to water table level and seedling age

Tree component	Tree age	Component age class	WT-4 + 10 + 20 (average)		WT-4	WT-10	WT-20	WT-4	WT-10	WT-20
	Year	*Year*	Ash, *percent*			N, *percent*			P, *percent*	
Needles	1 – 1	0 + 1	5.77	(.67)[1]	1.37c[2]	1.62b	1.97a	.14a	.14a	.17a
	1 – 2	0	3.92	(.70)	.62b	.67b	1.12a	.08a	.08a	.10a
		1 + 2	5.49	(.76)	.64b	.73b	1.00a	.07b	.06b	.08a
	1 – 3	0	4.32	(.22)	.76b	.65b	1.07a	.09a	.09a	.11a
		1	5.35	(.26)	.74b	.68b	1.05a	.07a	.08a	.08a
		2 + 3	6.49	(.42)	.68b	.65b	.98a	.07a	.07a	.07a
Shoots	1 – 1	0 + 1	1.68	(.25)	.80b	.86b	1.00a	.11a	.09a	.10a
	1 – 2	0	1.44	(.17)	.35b	.38b	.53a	.05b	.05b	.06a
		1 + 2	1.54	(.16)	.27b	.27b	.33a	.03a	.03a	.04a
	1 – 3	0	1.65	(.08)	.33a	.38a	.46a	.07a	.07a	.08a
		1	1.63	(.10)	.28a	.31a	.38a	.05a	.04a	.04a
		2 + 3	1.74	(.11)	.26a	.22a	.34a	.03a	.03a	.03a
Roots	1 – 1	—	3.85	(.59)	.66a	.68a	.85a	.10a	.08a	.09a
	1 – 2	—	3.63	(.52)	.50a	.45a	.52a	.05a	.05a	.05a
	1 – 3	—	4.11	(1.29)	.57a	.39b	.48ab	.06a	.05ab	.05a

Table 4.—Continued

Tree component	Tree age	Component age class	WT-4	WT-10	WT-20	WT-4	WT-10	WT-20	WT-4	WT-10	WT-20
	Year	*Year*		Ca, percent			K, *percent*			Mg, *percent*	
Needles	1 – 1	0 + 1	1.24a	.93b	1.02b	.75b	.83ab	.91a	.15ab	.14b	.16a
	1 – 2	0	.71b	.70b	.88a	.60ab	.53b	.69a	.12b	.12b	.15a
		1 + 2	1.29a	1.18a	1.24a	.36b	.37b	.61a	.10b	.10b	.13a
	1 – 3	0	.71a	.67a	.79a	.65a	.72a	.70a	.16ab	.14b	.19a
		1	1.15a	1.05a	1.30a	.33b	.54a	.55a	.15a	.14a	.15a
		2 + 3	1.54a	1.28a	1.48a	.40a	.35a	.50a	.14a	.12a	.17a
Shoots	1 – 1	0 + 1	.37a	.30b	.32ab	.26a	.21ab	.17b	.08a	.06a	.07a
	1 – 2	0	.27b	.29b	.34a	.14a	.14a	.16a	.05b	.05b	.07a
		1 + 2	.38a	.36a	.36a	.12a	.13a	.13a	.05a	.04a	.05a
	1 – 3	0	.27b	.30ab	.37a	.18a	.17a	.15a	.06a	.06a	.07a
		1	.31a	.34a	.37a	.23a	.19a	.19a	.05ab	.04b	.06a
		2 + 3	.37a	.37a	.38a	.12a	.10a	.12a	.05a	.04a	.05a
Roots	1 – 1	—	.25a	.25a	.27a	.38a	.36ab	.28b	.14a	.11b	.12ab
	1 – 2	—	.28c	.31b	.34a	.29a	.31a	.27a	.12a	.12a	.13a
	1 – 3	—	.26b	.29ab	.33a	.31a	.29a	.34a	.15a	.11a	.14a

Table 4.—Continued

Tree component	Tree age	Component age class	WT-4	WT-10	WT-20	WT-4	WT-10	WT-20	WT-4	WT-10	WT-20
	Year	*Year*		Mn, *percent*			Zn, *mg/kg*			Cu, *mg/kg*	
Needles	1 – 1	0 + 1	.21a	.15b	.11b	222a	272a	244a	16a	12b	11b
	1 – 2	0	.27a	.18b	.12c	116b	163a	189a	3a	2a	3a
		1 + 2	.30a	.18b	.12c	229b	312a	297a	4ab	3b	5a
	1 – 3	0	.41a	.25b	.12c	128a	125a	141a	10a	9a	8a
		1	.54a	.30b	.15c	205a	217a	238a	10a	9a	8a
		2 + 3	.48a	.28b	.13c	269a	282a	292a	10a	8b	8b
Shoots	1 – 1	0 + 1	.07a	.05b	.03c	120a	139a	127a	17a	15b	12c
	1 – 2	0	.10a	.07b	.03c	72b	101a	105a	8a	8a	7a
		1 + 2	.09a	.06b	.03c	93b	118a	95b	8a	8a	6b
	1 – 3	0	.14a	.10b	.04c	99a	95a	92a	10a	7b	6b
		1	.14a	.08b	.03c	99a	107a	94a	7a	5a	7a
		2 + 3	.12a	.07b	.03c	101a	101a	90a	7a	7a	10a
Roots	1 – 1	—	.06a	.04b	.03c	114b	155a	118b	19a	18ab	16b
	1 – 2	—	.08a	.05b	.02c	116a	145a	134a	17a	14b	9c
	1 – 3	—	.11a	.08b	.03c	126a	130a	125a	17a	13b	13b

Table 4.—Continued

Tree component	Tree age	Component age class	WT-4	WT-10	WT-20	WT-4	WT-10	WT-20	WT-4 + WT-10 + WT-20 (average)	
	Year	*Year*		Fe, *mg/kg*			B, *mg/kg*			Al, *mg/kg*
Needles	1 – 1	0 + 1	181ab	215a	120b	56a	61a	66a	270	(132)
	1 – 2	0	95b	90b	183a	54b	56b	66a	238	(117)
		1 + 2	270b	155b	465a	65a	69a	75a	481	(177)
	1 – 3	0	145a	135a	164a	67a	60a	64a	268	(41)
		1	160b	252a	222ab	76a	72a	69a	389	(59)
		2 + 3	415b	437a	446a	84a	74a	84a	667	(66)
Shoots	1 – 1	0 + 1	145a	92ab	55b	15a	14a	14a	108	(58)
	1 – 2	0	119a	48b	54b	14a	13ab	12b	96	(16)
		1 + 2	99a	86a	80a	12b	15a	11c	144	(21)
	1 – 3	0	69a	70a	77a	13a	13a	11a	116	(15)
		1	74a	81a	68a	13a	12a	10a	123	(16)
		2 + 3	120a	165a	86a	8a	8a	9a	204	(43)
Roots	1 – 1	—	1839a	1096a	1214a	24a	21ab	16b	1481	(225)
	1 – 2	—	4660a	1059b	1029b	32a	23b	17b	2257	(348)
	1 – 3	—	5967a	1387b	996b	32a	19b	16b	2916	(594)

[1]Standard deviations are in parentheses.
[2]Letters designate difference due to soil drainage conditions during the same year at the 0.05 level using Duncan's New Multiple Range Test.

Table 5.—Summary of analysis of variance showing significant effect for nutrient concentration in black spruce growing in soil with three different water table levels

Source of variation	Ash	N	P	Ca	K	Mg	Mn	Fe	Al	Zn	B	Cu	Na
	"F" values												
							NEEDLES						
Water level (W)	3*	97**	8**	15**	20**	30**	249**	5**	—	12**	3*	6*	6**
Age (A)	29**	138**	39**	80**	45**	20**	44**	22**	19**	37**	8**	62**	—
Interaction (WxA)	2*	—	—	3**	2*	—	12**	4**	3**	—	—	—	—
							SHOOTS						
Water level (W)	3*	16**	—	3*	—	12**	392**	13**	13**	9**	6**	7**	14**
Age (A)	6**	113**	62**	9**	13**	19**	36**	4**	16**	13**	14**	71**	3*
Interaction (WxA)	3**	—	—	3**	—	2*	8**	3**	2*	—	—	4**	—
							ROOTS						
Water level (W)	6*	3*	4*	21**	—	5**	196**	96**	8**	5*	32**	38**	3*
Age (A)	—	21**	54**	35**	—	—	46**	18**	55**	—	4*	41**	5*
Interaction (WxA)	—	—	—	—	—	—	14**	19**	—	—	—	5**	6**

*Significant at 5-percent level
**Significant at 1-percent level

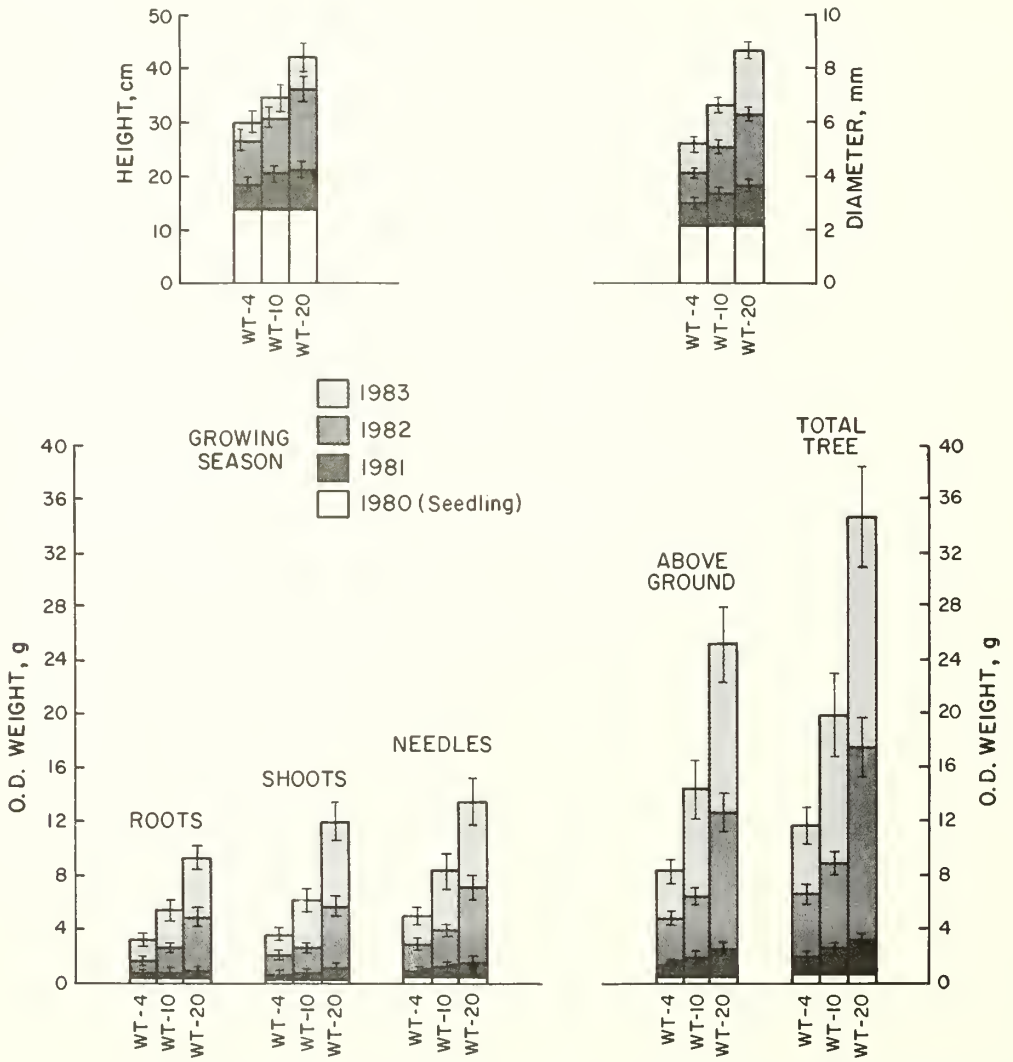

Figure 1.—Mean diameter, height, and component biomass of black spruce as related to water table level.

significant differences in concentrations of P were found due to water table level. For Zn, the differences were significant but did not follow any trend.

Concentrations of ash and all mineral elements except Fe and Cu varied with the age of seedling shoots. The overall mean concentrations of ash, Ca, Al, Fe, and Zn increased and those of N, P, K, Mg, and B decreased with increasing shoot age. The increases of Cu and Mn concentrations were somewhat inconsistent in respect to component age class. The values were also affected by wood-bark ratio, which was not quantified in this study, for respective tree ages.

Roots. Along the gradient of water table depth from 4 to 20 cm, the mean concentration of N and Ca in roots significantly increased and that of ash, Mn, B Fe, Al, and Cu significantly decreased. The values for P, Mg, and Zn were significantly different but did not follow any trend. Concentrations of K did not significantly differ between three water levels.

Mean concentration of ash, Fe, Mn, Na, and Al significantly increased and N, P, and Cu significantly decreased with increasing tree age. The overall concentrations of K, Mg, Zn, and B did not significantly differ between 1-, 2-, and 3-year-old trees.

Changes in element concentrations in trees growing under different soil water table levels were consistent with results reported in the literature. This is due to an aerobic to anaerobic gradient in soil conditions with progressively poorer soil drainage. It is not surprising that in the absence of oxygen nutrient absorption by roots in the majority of the trees is significantly curtailed, because roots grow very poorly in waterlogged soils. It appears that black spruce has some degree of tolerance to high water tables, but the mechanism is unknown to the authors.

The differences in inorganic element concentrations that occurred with plant age were consistent with the literature. Concentrations of Ca rapidly increased between current and older tree components. On the other hand, concentrations of N, P, K, and some micronutrients decreased sharply between the first and second growing seasons. This decrease was partly due to dilution by tree growth as well as due to fertilization of seedlings prior to the first growing season in the greenhouse, with nutrient reserves by the end of the first year likely being exhausted.

Comparisons with Published Data

To examine the relationships among nutrients in foliage, studies by Ingestad (1967), Weetman (1968), and Adams and Allen (1985) utilized nutrient proportions, expressing all nutrient concentrations relative to N concentration which is taken to be 100 percent. Consequently, we compared our data on current year foliage with those suggested by Ingestad (1967) for optimum nutrient proportions, with the levels given by Weetman (1968) for untreated mature black spruce stands and by Swan (1969) for levels sufficient for good to very good growth of black spruce seedlings (Table 6).

Table 6.—Comparisons among current year's foliar nutrient concentrations and proportions of black spruce reported by several authors

Nutrient	Current study				Ingestad (1966, 1967) (Seedlings, optimum proportion)	Swan (1969) (seedlings, for good growth)	Weetman (1968) (mature stand untreated)
	Cont. Seedlings	WT-4	WT-10	WT-20			
N							
Percent	1.43	0.69	0.66	1.10	—	1.50-2.50	0.94
Proportion	100	100	100	100	100	100 100	100
P							
Percent	0.27	0.08	0.08	0.10	—	0.18-0.30	0.19
Proportion	19	12	12	9	8-15	12-12	20
K							
Percent	1.08	0.62	0.62	0.70	—	40-80	0.53
Proportion	76	90	94	64	50-100	27-32	56
Mg							
Percent	0.13	0.14	0.13	0.17	—	0.12-0.25	0.14
Proportion	9	20	20	15	5-10	8-10	15
Ca							
Percent	0.71	0.71	0.68	0.84	—	0.15-0.40	0.36
Proportion	50	103	103	76	5-10	10-16	38

Data in Table 6 show that the foliage of containerized seedlings prior to planting exhibited sufficient levels of N, P, and Mg for good to very good growth, and those of K and Ca are considered to be far above the optimum levels.

In planted seedlings, the relationships in the current year's foliage during the second and third growing seasons drastically changed. Concentrations of N on plots with 4 and 10 cm to the water table decreased to the levels of acute deficiency, and those with 20 cm to the water table decreased to the levels of moderate deficiency. Concentrations of P dropped to the levels of acute deficiency on all plots. Concentrations of K and Mg remained at levels sufficient for good to very good growth, and those of Ca remained at luxury consumption levels.

With decreasing N concentration, there was an increase in relative concentration of K, Mg, and Ca. Because of the decrease in absolute concentration of P, a decrease in relative levels has to be expected.

Comparisons of nutrient levels reported in this study for branches, shoots, and roots were not made because data on macro-nutrient levels in black spruce components other than the current year's foliage is nonexistent.

Furthermore, comparisons of nutrient levels reported in this study with those required for adequate or optimum growth cannot be made because information on macro-nutrient levels in black spruce components, other than the current year's foliage, is also nonexistent. Therefore, until furtner data become available it seems reasonable to accept the levels and ranges given by Young and Carpenter (1967) for branches, stems, and roots of red spruce, by McKee and others (1984) for 2-year-old loblolly pine (Pinus taeda L.) grown under flooded and drained soil conditions, and by Czapowskyj (1979) for balsam fir as affected by soil drainage. Elemental levels in the foliage, shoots, and roots reported in the current study are generally comparable, and the trends are consistent with those reported by authors referred to above for the respective tree components of other coniferous species.

Conclusions

The following conclusions can be drawn from these results:

- Containerized seedlings received adequate nourishment for good to very good growth during the initial growth period.
- Survival of black spruce seedlings was not affected by water table depths of 4, 10, and 20 cm during a period of 3 years following transplanting.
- An increase of the water table depth below the mineral soil surface significantly enhanced the growth and biomass production of the foliage, shoots, and roots.
- As the depth to the water table increased: (a) the levels of N increased and those of Na, Mn, Cu, and Al decreased in foliage, shoots, and roots; and (b) the levels of P, K, Zn, Fe, and B increased only in the foliage and Mg increased in both foliage and shoots.
- A positive response in black spruce growth would be expected if plantations were established on sites where the water table could be maintained to a depth of at least 20 cm.

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The objective of this study was to determine the effect of different soil water table levels on growth, biomass production, and nutrient accumulation in black spruce seedlings growing under greenhouse conditions over three growing seasons after transplanting.

ODC 181.32 *Picea mariana* (Mill) B.S.P.

Keywords: black spruce biomass, water table, nutrients

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Produce Yellow-Poplar Furniture Dimension at Minimum Cost by Using YELLOPOP

David G. Martens

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Abstract

Describes a computer program called YELLOPOP that determines the least-cost combination of lumber grades required to produce a given cutting order of yellow-poplar furniture dimension parts. If the least-cost mix is not available, YELLOPOP can be used to determine the next best alternative. The steps to use the program are described.

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Yellow-poplar continues to be an important raw material in the U.S. furniture industry. Although its use as a core material has been largely replaced by particleboard, yellow-poplar still accounts for about 20 percent of the furniture industry's total lumber requirements.

To assist the hardwood furniture and dimension industries, a computer program called YELLOPOP has been developed by the USDA Forest Service to facilitate the production of yellow-poplar furniture dimension at minimum cost. YELLOPOP determines the least-cost combination of yellow-poplar lumber grades required to produce a given cutting order of dimension parts. If that combination is not available, YELLOPOP can be used to determine the next best alternative. In addition, it can be used as a decisionmaking tool to evaluate numerous day-to-day problems in the management of a furniture rough mill.

YELLOPOP Program

The YELLOPOP analysis uses a linear programing technique to correlate the cost associated with each grade of yellow-poplar lumber with the predicted yields of each cutting size obtainable from that grade. This correlation leads to the combination with the lowest total cost.

The yield values for each grade were developed from the charts published in "Dimension Yields from Yellow-Poplar Lumber" (Gilmore et al. 1984). The actual numerical yield values for random-width pieces and the yield adjustments for cuttings of specific widths for Firsts and Seconds (FAS), First and Seconds One Face (F1F), No. 1 Common (1C), No. 2A Common (2A), and No. 2B Common (2B) are extrapolated from the yield values in Tables 1–10 (Appendix). Yields are based on 4/4 kiln-dried yellow-poplar lumber (Volumes refer to lumber measured in the dry condition). The dimension cuttings from all grades are clear, two-face, with the exception of the No. 2B grade yields, which are for sound two-face cuttings. The yield values are not necessarily the maximum attainable from any individual board. Rather, they simulate a highly skilled operator who can make consistently good decisions on where to place the saw lines. Therefore, the predicted yields should be achievable in a well-run rough mill.

Cutting orders containing pieces of any length from 10 to 96 inches and pieces with specific widths (no glueline) up to 5-1/2 inches can be evaluated by YELLOPOP. However, the maximum length piece obtainable from each grade is limited to: 96 inches for FAS; 96 inches for F1F; 80 inches for No. 1C; 40 inches for No. 2A; and 40 inches for No. 2B.

The yield values contained in Tables 1–10 are based on the longest length cutting obtained from each grade. For example, if the longest length obtained from FAS grade was 90 inches, Table 1 shows that for every thousand board feet (M bf) of rough FAS lumber input, you can expect a yield of 400 net board feet (or 40 percent) of 90-inch long cuttings that are 1 inch and wider (random width). If you want only 2-inch-wide pieces that are 90 inches long, Table 2 shows that the yield value must be reduced by 22 net board feet. Therefore, the predicted yield of 90-inch-long by 2-inch-wide cuttings is 378 net board feet for every M bf input. Yields for subsequent (shorter) cuttings from FAS are derived from the column of yields having 90 inches as its longest length. If the next length to come from FAS is 70 inches, the predicted yield is 533 net board feet per M bf input (Table 1). However, if the available 378 net board feet of 90 x 2-inch cuttings were already removed, the yield of 70-inch random-width cuttings is actually 155 net board feet (533-378) for each M bf input. The predicted yield of each shorter subsequent cutting would be calculated in a similar fashion. Although the process is very time-consuming to do longhand, the computer can evaluate all possible combinations of cutting sizes and lumber grades easily.

Data Entry

The data entry screen for the YELLOPOP program is shown in Figure 1. For later reference, you enter the date, name or model number of the cutting order, and the thickness of the lumber required. The input factors used by the program include the cost per M bf associated with each grade of yellow-poplar that you wish to have considered in the possible least-cost mix, adjustments you want to make to the predicted yields for each grade, and volume constraints you want placed on the grades.

The cost of each grade, expressed in dollars per M bf, should represent the sum of all costs associated with that grade through the rough mill. Cost items to be included are at the discretion of the user but could include the cost for lumber purchase, delivery, drying and handling, rough mill cut-up, inventory, and overhead.

The yield adjustment factor can be used to modify the predicted yields of any grade. Acting as a percentage adjustment to the predicted yields, the yield adjustment factor can be used to adapt the basic yields for admissible defects, thicknesses of lumber over 4/4, or general rough-mill efficiency.

The volume constraints are used to limit the amount of a grade being considered. The resulting YELLOPOP analysis may or may not use all of the grade in limited supply, but the least-cost grade mix will never contain more of that grade than the volume allowed. This feature of the program is generally used in determining the next best alternatives.

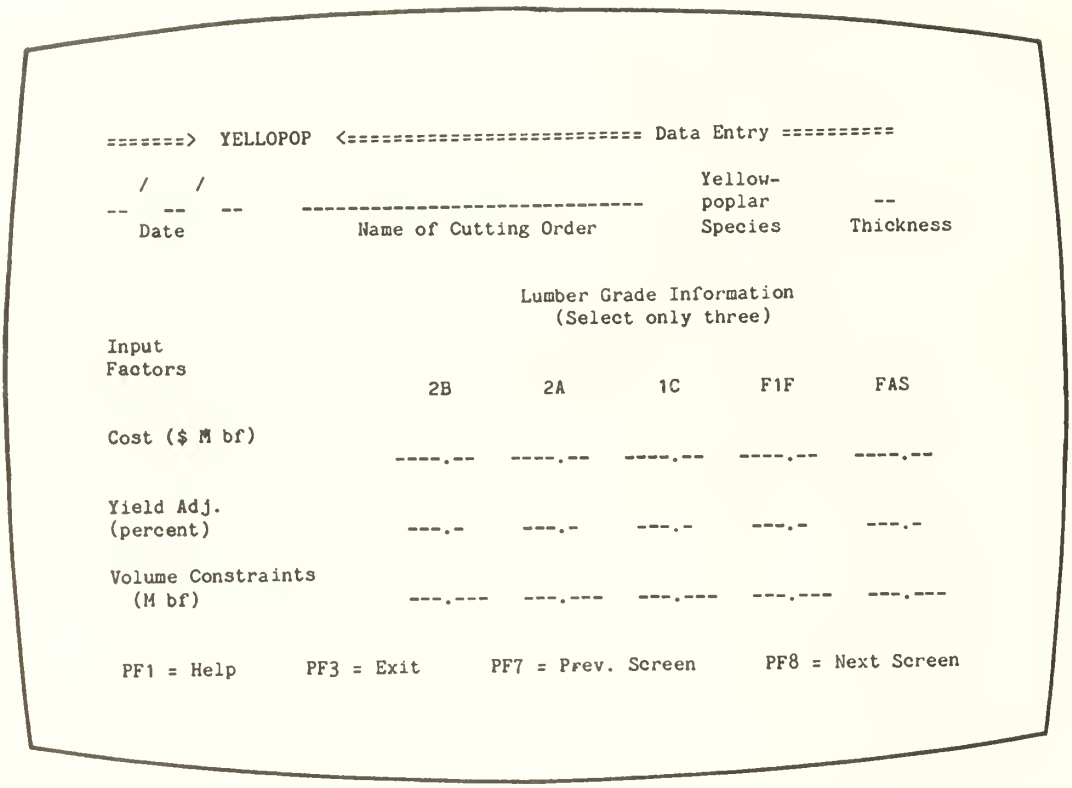


Figure 1.—Blank Data Entry screen.

Cutting Order

Now that the grades and their associated costs have been established, the individual sizes of the pieces to be obtained are entered on the Cutting Order screen shown in Figure 2. Each size of cutting is entered by length, width, type, and number of pieces required. Up to 50 different sizes of cuttings can be entered. The type of cutting refers to whether it is of a specified width (no glueline) (S) or glued up from random widths (R).

YELLOPOP Printout

The YELLOPOP printout consists of four sections: (1) the input information evaluated, (2) the least-cost grade mix, (3) the range and sensitivity analysis, and (4) the cutting instructions for obtaining the desired cuttings. The first three sections are meant to be retained by management and filed for future reference. The last section would go to the rough-mill foreman for use in establishing the cutting instructions.

Input Information

The first section (Fig. 3) provides a record of the lumber costs used, any adjustments made, and the cutting order evaluated. Since individual cutting orders recur, it can be saved and used in making future management decisions.

Least-Cost Grade Mix

The second section provides the least-cost grade mix solution (Fig. 4). For each grade of lumber, the printout shows the predicted lumber volume required, the grade's contribution to the total production cost, the net board feet of cuttings to be obtained from it, the percent yield, and the totals of these items for the entire cutting order.

This solution represents the best that we can do under the costs and conditions we have specified. There is no other combination of grades and volumes that will result in a lower total cost.

Range and Sensitivity Analysis

The range and sensitivity analysis (Fig. 4) is the key to using YELLOPOP as a decisionmaking tool. It indicates how good our current least-cost grade mix is relative to the next best alternatives. As such, it also indicates how we might allocate our lumber when less than optimal conditions exist.

CUTTING ORDER

Item No.	Length (in.)	Width (in.)	R/S*	Number of pieces	Item No.	Length (in.)	Width (in.)	R/S*	Number of pieces
(1)					(2)				
(3)					(4)				
(5)					(6)				
(7)					(8)				
(9)					(10)				
(11)					(12)				
(13)					(14)				
(15)					(16)				
(17)					(18)				
(19)					(20)				
(21)					(22)				
(23)					(24)				
(25)					(26)				
(27)					(28)				
(29)					(30)				

PF1 = Help PF3 = Exit PF7 = Prev. Screen PF8 = Next Screen

CUTTING ORDER

Item No.	Length (in.)	Width (in.)	R/S*	Number of pieces	Item No.	Length (in.)	Width (in.)	R/S*	Number of pieces
(31)					(32)				
(33)					(34)				
(35)					(36)				
(37)					(38)				
(39)					(40)				
(41)					(42)				
(43)					(44)				
(45)					(46)				
(47)					(48)				
(49)					(50)				

PF1 = Help PF3 = Exit PF7 = Prev. Screen PF8 = Go to File Screen Options

Figure 2.—Cutting Order, screen 1 and screen 2.

INPUT INFORMATION SECTION OF YELLOPOP PRINTOUT

March 20, 1986--dresser--Yellow-poplar

Lumber grade	Production costs (dollars/M bf)	Grade yield adjustment factor	Volume constraints (M bf)	Lumber thickness (inches)
Number 2A Common	362.00	95.0	None	4/4
Number 1 Common	430.00	95.0	None	4/4
Firsts and Seconds	570.00	95.0	None	4/4

--Input Cutting Order--

Cutting size Length (inches)	Width (inches)	Type of cutting random (R) or specified (S)	Number of cuttings	Net board feet of cuttings
27.750	20.000	R	25	96.4
15.500	22.000	R	240	568.3
60.750	2.250	S	1000	949.2
58.125	2.250	S	3500	3178.7
31.375	3.250	S	1000	708.1
31.375	2.250	S	1000	490.2
30.000	1.750	S	1000	364.6
28.312	0.750	S	500	73.7
20.250	2.250	S	500	158.2
19.250	0.750	S	500	50.1
18.250	1.250	S	2500	396.1
18.000	2.625	S	1000	328.1
18.000	1.250	S	1000	156.2
17.000	2.250	S	3500	929.7
16.500	3.000	S	1500	515.6
16.500	2.000	S	2000	458.3
14.250	2.250	S	500	111.3
Totals			21265	9533.0

Figure 3.—Input information section.

LEAST-COST GRADE MIX SOLUTION

March 20, 1986--Aztec Dresser--Yellow-poplar

-- Summary by Grade --

Selected grades	Input cost/M bf (dollars)	Gross volume (M bf)	Total production cost (dollars)	Board feet of cuttings	Percent yield
Number 2A Common	362	1.978	716	1092.7	55.2
Number 1 Common	430	14.777	6353	8014.7	54.2
Firsts and Seconds	570	0.642	365	425.6	66.3
Totals		17.396	7435	9533.0	54.8

-- Range and Sensitivity Analysis Information --

Selected grades		Input cost and levels/M bf (dollars)	Associated gross volumes (M bf)
Number 2 Common	Upper	363.60	1.921
		362.00	1.978
	Lower	328.19	1.992
Number 1 Common	Upper	440.28	14.731
		430.00	14.777
	Lower	429.56	14.985
Firsts and Seconds	Upper	570.76	0.521
		570.00	0.642
	Lower	552.25	0.668

Figure 4.—Least-cost grade mix solution.

The range and sensitivity analysis shows the range over which the input cost of each grade can move without a change in the least-cost grade mix, assuming the input cost of the other grades remains unchanged. By varying the input cost of one grade while holding the others constant, the program determines at what level of input cost there would be a change in how the grades are used to obtain the cuttings required. The "associated gross volumes" then show the volume of the grade that would be used at that input cost.

Figure 4 shows that if the input cost of FAS increased by 76 cents per M bf, the volume of FAS used in the alternative least-cost mix would drop by 121 board feet to 521 board feet. Although hardly earth-shaking, an astute manager may see this as an indication that FAS could be eliminated entirely. If, in fact, YELLOPOP is rerun without any FAS, it would be found that a mix of 15.884 M bf of No. 1C and 1.673 M bf of No. 2A would result in a total cost of $7,436 or only $1.00 more than our least-cost mix. As a matter of fact, both FAS and No. 2A could be eliminated for an additional $46 over the least-cost mix. The capability to evaluate the cost of different options can be a help to managers.

For a more complete discussion of the interpretation of the range and sensitivity analysis and how it can be used as a decisionmaking tool, obtain a copy of "OPTIGRAMI: Optimum Lumber Grade Mix for Hardwood Dimension Parts" (Martens and Nevel 1985).

Cutting Instruction

The last section of the YELLOPOP printout is the cutting instruction (Fig. 5) for obtaining the required dimension cuttings from the proposed least-cost mix. The rough-mill foreman uses this section to assign cutting lengths to specific crosscut saw operators.

It provides the input volume of each grade according to the least-cost mix, the cutting sizes that are to be obtained from each grade, and the number of pieces that are expected from that volume of lumber.

The program evaluates all combinations of cutting requirements and yield per grade to determine the least-cost combination. The results are not always according to tradition. For example, in the cutting instructions shown (Fig. 5), the longest length in the cutting order (60.750 inches) is obtained exclusively from No. 1C and not FAS. Instead, FAS is used to supplement the requirements for 58.125-, 17.000-, and 15.500-inch cutting lengths and provide all of the 28.312- and 19.250-inch cutting lengths. The fact that FAS was used to supplement relatively short lengths helps explain how it could be completely eliminated from the mix at a total added cost of $1.00.

This last section also provides a value called "board feet shorts." This represents the net board feet of unused volume that would be available as 10-inch-long, random-width cuttings. As such, it provides an indication of how well the raw material is being utilized.

In addition to the information on each grade, the entire cutting order is summarized. Included in the summary are the total gross volume of lumber required, the total net board feet of cuttings to be obtained, the total board feet of shorts anticipated, and the total number of pieces required.

Using YELLOPOP

YELLOPOP is designed for use on any IBM mainframe computer with a mathematical programing system (MPS) in its program library. The program can be accessed through an on-site computer or through a remote terminal.

Remote Terminal

For those using a remote terminal, YELLOPOP has been placed on the Computerized Management Network (CMN), a national time-sharing computer service managed by the Virginia Cooperative Extension Service. Access to CMN can be made on any ASCII terminal and a modem or on a microcomputer with a communications program.

The CMN is accessed through normal long distance telephone lines. To LOG ON, you will need to obtain a CMN user identification number (userid) and password by contacting:

Virginia Polytechnic Institute and State University
Virginia Cooperative Extension Service
Extension Computing Resources
Plaza I, Building D
Blacksburg, Virginia 24061
703–961–5184

There is no initial fee or hookup charge for CMN, but there is a small monthly userid ownership charge.

To use the program, you simply dial the computer telephone number and LOG ON with your CMN userid and password. The computer will then ask you what program you would like and you enter "YELLOPOP." The Main Menu screen, shown in Figure 6, will appear and asks what you would like to do. By pressing one of the four function (PF) keys, you can request a file for editing or analysis (PF4), determine if a submitted analysis has been returned to your userid (PF5), get the HELP file (PF1), or exit from the program (PF3). For example, if you wish to make a YELLOPOP analysis, you press the PF4 key. A screen appears that asks you to enter a file name (Fig. 7). It also lists all the file names that you have previously run. To enter a file name, you may either (a) enter a name of from one to eight characters in the file name field and then

OPTIMUM SOLUTION CUTTING INFORMATION

March 30, 1986--Aztec Dresser--Yellow-poplar

Selected grades	Lumber thickness (inches)	Gross volume (M bf)	Cutting size Length	Width	Type of cutting	Number of cuttings	Net board feet
			--(inches)--				
Number 2A Common	4/4	1.978					
			27.750	20.000	R	25	96.4
			15.500	22.000	R	200	473.9
			18.000	2.625	S	981	321.8
			18.000	1.250	S	994	155.4
			14.250	2.250	S	203	45.3
Net Board Feet/Grade = 1092.7							
Board Feet Shorts = 174.1							
Number 1 Common		14.777					
			15.500	22.000	R	37	88.7
			60.750	2.250	S	1000	949.2
			58.125	2.250	S	3183	2890.9
			31.375	3.250	S	1000	708.1
			31.375	2.250	S	1000	490.2
			30.000	1.750	S	1000	364.6
			20.250	2.250	S	500	158.2
			18.250	1.250	S	2500	396.1
			18.000	2.625	S	19	6.3
			18.000	1.250	S	6	0.9
			17.000	2.250	S	3469	921.5
			16.500	3.000	S	1500	515.6
			16.500	2.000	S	2000	458.3
			14.250	2.250	S	297	66.1
Net Board Feet/Grade = 8014.7							
Board Feet Shorts = 369.9							
Firsts and Seconds		0.642					
			15.500	22.000	R	2	5.8
			58.125	2.250	S	317	287.8
			28.312	0.750	S	500	73.7
			19.250	0.750	S	500	50.1
			17.000	2.250	S	31	8.2
Net Board Feet/Grade = 425.6							
Board Feet Shorts = 21.8							

Total Gross Volume (M bf)	Total Net Board Feet	Total Shorts (bf)	Total Number of Pieces
17.396	9533.0	565.8	21264

Figure 5.—Optimum solution cutting information.

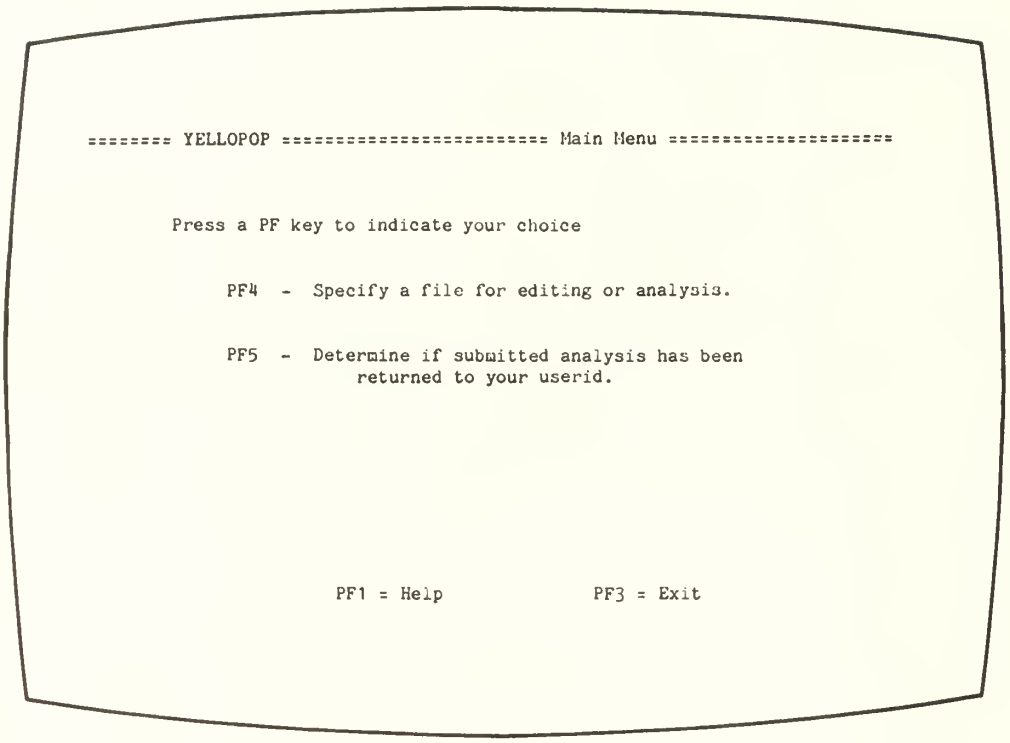

======== YELLOPOP ========================== Main Menu ======================
Press a PF key to indicate your choice
PF4 - Specify a file for editing or analysis.
PF5 - Determine if submitted analysis has been returned to your userid.
PF1 = Help
PF3 = Exit

Figure 6.—Main Menu.

press the ENTER key, or (b) position the cursor at the name of one of your existing files and then press ENTER (this copies the name at the cursor to the file name field at the top of the screen); then press ENTER again to validate the name you have selected. A message will appear at the bottom of the screen indicating that the requested file is an old file.

Now that you have selected your file, press the PF8 key, as shown at the bottom of the screen, to proceed to the File Options screen (Fig. 8). As shown, you press a PF key to select whether you want to edit the selected file (PF4), submit the file for processing (PF5), or specify your job priority (PF6).

Since we are interested in making an analysis, we would press PF4 to proceed to the Data Entry screen shown earlier in Figure 1. Fields for all necessary data input are labeled. These include date, cutting order name, thickness, lumber grades to be selected and their respective costs, yield adjustments, and volume constraints. On the Data Entry screens, you can move the cursor with the cursor controls or skip from field to field with the TAB key.

In the example Data Entry screen (Fig. 9), we have specified 4/4 thickness and the lumber grades of 2A, 1C, and FAS. The input costs of $362, $430, and $570, respectively, reflect estimates of the total of costs for each grade through the rough mill. The 95 percent yield adjustment is for demonstration purposes only. Since no volume constraints were used, the program assumes that there are unlimited volumes available for each grade. We would now press PF8 to move to the next screen, which is where we enter our cutting order (Fig. 10). YELLOPOP can accommodate 50 specific cutting sizes (30 on this screen and 20 on the next screen). Each is entered by length, width, type, and number of pieces. An R is used for panels that will be glued up from random-width pieces, and S is used when each part is to have a specified width (no glueline). Part sizes do not need to be entered in a particular order, such as from longest to shortest lengths.

Pressing the PF8 key takes us to screen 2 of the cutting order and pressing PF8 again takes us back to the File Options screen (Fig. 8). If we press PF6 on the File Options screen, we can specify our job priority (Fig. 11). Five levels of priority can be selected from idle (least expensive) to urgent (most expensive). If no selection is made, the program is preset to run on idle priority. Assuming that we are satisfied with our priority, we press PF5 to submit our file for processing. We will receive a message at the bottom indicating that "YELLOPOP job submitted. Check for results after 10 minutes."

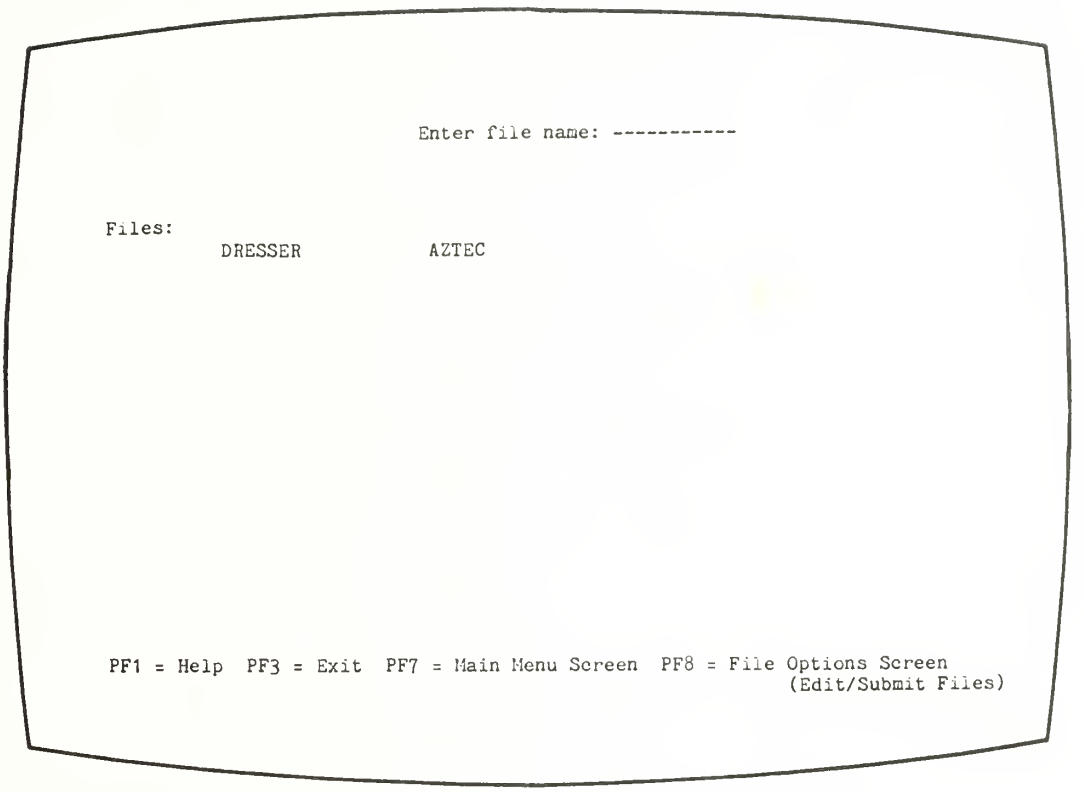


Figure 7.—File Name screen.

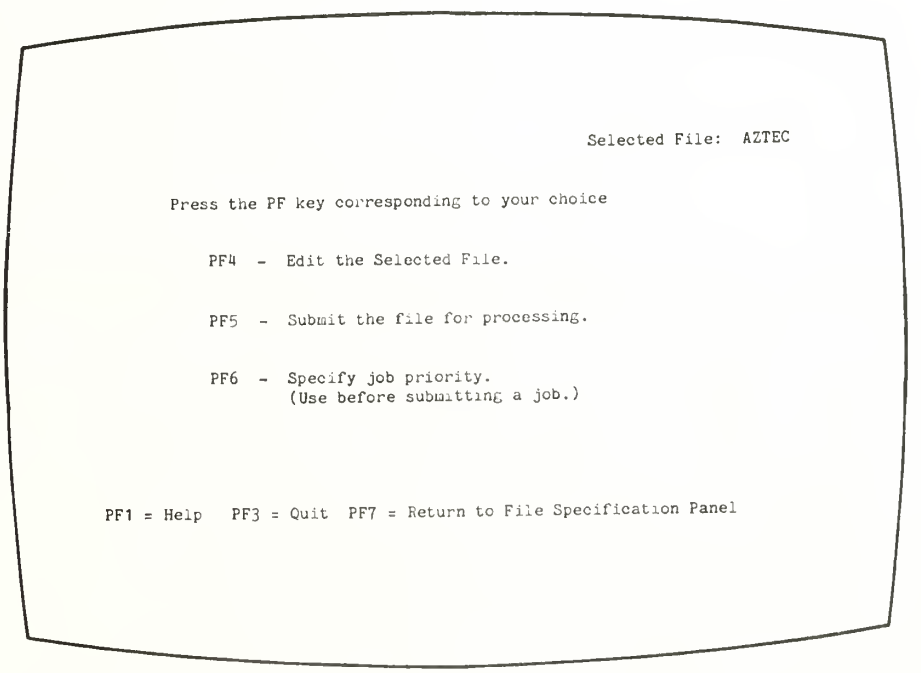

Selected File: AZTEC
Press the PF key corresponding to your choice
PF4 - Edit the Selected File.
PF5 - Submit the file for processing.
PF6 - Specify job priority.
(Use before submitting a job.)
PF1 = Help PF3 = Quit PF7 = Return to File Specification Panel

Figure 8.—File Options screen.

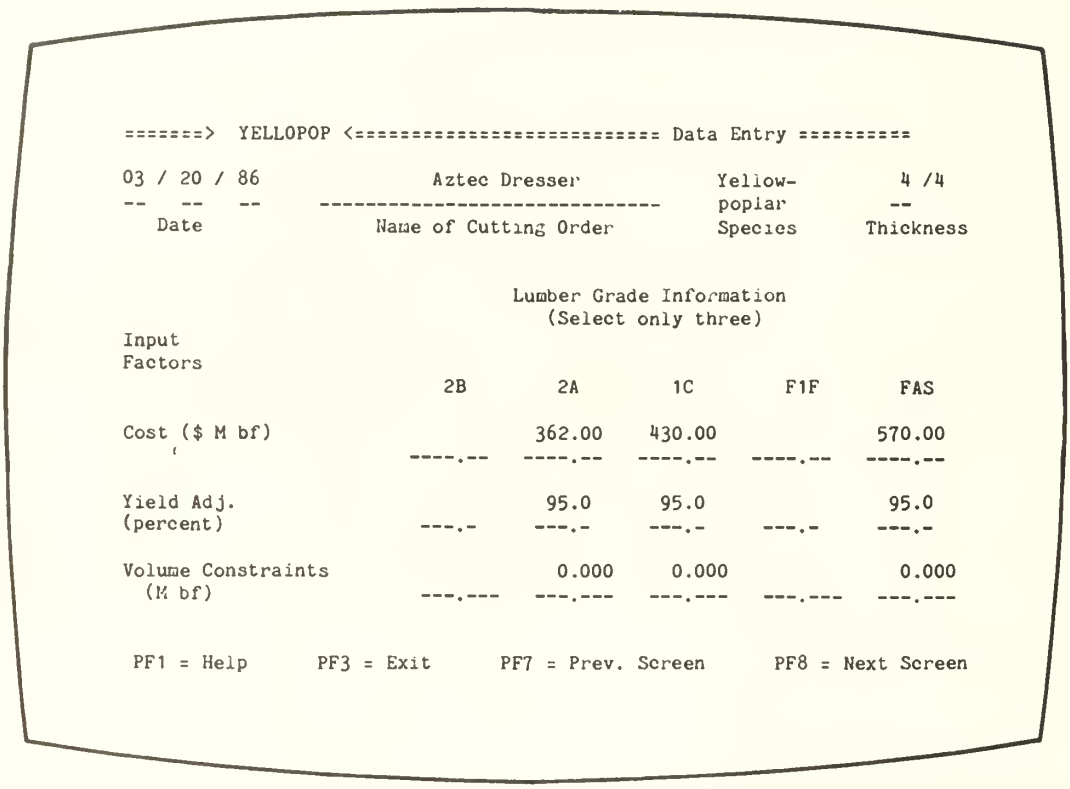


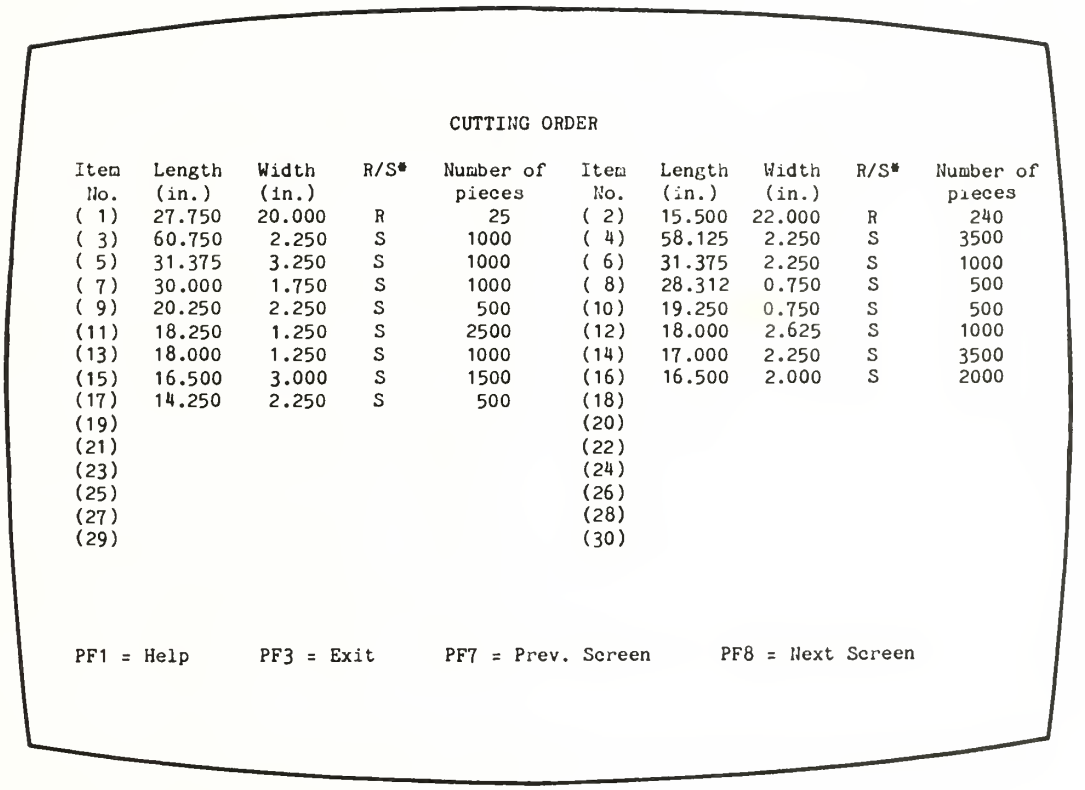
Figure 9.—Completed Data Entry screen.

We can now press PF4 to make changes in our file if we want to rerun it with different lumber input costs, yield adjustments, or volume constraints. If we want to enter another analysis, we can press PF7 to go back to the File Specification screen (Fig. 7).

To receive our YELLOPOP output, we return to the Main Menu screen (Fig. 5) and press the PF5 key to determine if our submitted analysis has been returned to our userid. If it has not come back, we will receive a message at the bottom of the screen saying, "No YELLOPOP output has been returned. Try again later." When the analysis is completed, the output is returned to our "reader." To look at the output, we press PF11 as indicated on the screen. This makes the entire YELLOPOP output available to you. You can look through it by using the PF8 and PF7 keys to scroll forward and backward, respectively.

If you wish to keep the output, you press the PF9 key to have it recorded onto your CMN disk space as a permanent record or to have it printed. If you have a printer attached to your terminal, you can have your results printed by using the command "TPRINT" followed by the file name that you used in your File Name screen shown in Figure 7. You can also discard the output by pressing the PF2 key or have it printed at Virginia Polytechnic Institute and State University (VPI&SU) by pressing the PF4 key. VPI&SU will then send you the results. By pressing the PF3 key, you will be returned to the Main Menu.

On every screen requiring the selection of an option or the input of data, the PF1 key has been labeled HELP. After pressing it, a help file will be displayed on the screen to explain each of the options available to you.



CUTTING ORDER

Item No.	Length (in.)	Width (in.)	R/S*	Number of pieces	Item No.	Length (in.)	Width (in.)	R/S*	Number of pieces
(1)	27.750	20.000	R	25	(2)	15.500	22.000	R	240
(3)	60.750	2.250	S	1000	(4)	58.125	2.250	S	3500
(5)	31.375	3.250	S	1000	(6)	31.375	2.250	S	1000
(7)	30.000	1.750	S	1000	(8)	28.312	0.750	S	500
(9)	20.250	2.250	S	500	(10)	19.250	0.750	S	500
(11)	18.250	1.250	S	2500	(12)	18.000	2.625	S	1000
(13)	18.000	1.250	S	1000	(14)	17.000	2.250	S	3500
(15)	16.500	3.000	S	1500	(16)	16.500	2.000	S	2000
(17)	14.250	2.250	S	500	(18)				
(19)					(20)				
(21)					(22)				
(23)					(24)				
(25)					(26)				
(27)					(28)				
(29)					(30)				

PF1 = Help PF3 = Exit PF7 = Prev. Screen PF8 = Next Screen

Figure 10.—Cutting order.

Mainframe

If potential users have access to an IBM mainframe computer, they may wish to obtain a copy of our YELLOPOP program library. If you send a blank tape to the Forestry Sciences Laboratory, P. O. Box 152, Princeton, West Virginia 24740, we will have our YELLOPOP program library copied onto it and return it to sender with documentation of its contents. There will be no charge to the user.

If the IBM mainframe in question does not have an MPS package in its program library, it will be necessary to obtain it before YELLOPOP will function. An MPSX can be obtained from an IBM representative or an MPSIII can be obtained from Ketron, Inc., Management Science System Divisions, 1400 Wilson Boulevard, Arlington, Virginia 22209.

All features and capabilities available on the CMN version are also available on the mainframe version and they are operated identically.

Summary

YELLOPOP can make a significant difference in the total cost of yellow-poplar dimension parts by selecting the most economical combination of grades and volumes required to produce a given cutting order. YELLOPOP and its companion programs, OPTIGRAMI and WALNUT (Martens 1986), are decisionmaking tools designed to help furniture rough-mill managers. OPTIGRAMI is used to evaluate cutting orders from all species graded by the standard National Hardwood Lumber Association's rules and WALNUT is used for walnut. They are easy to use and are adaptable to individual plant situations.

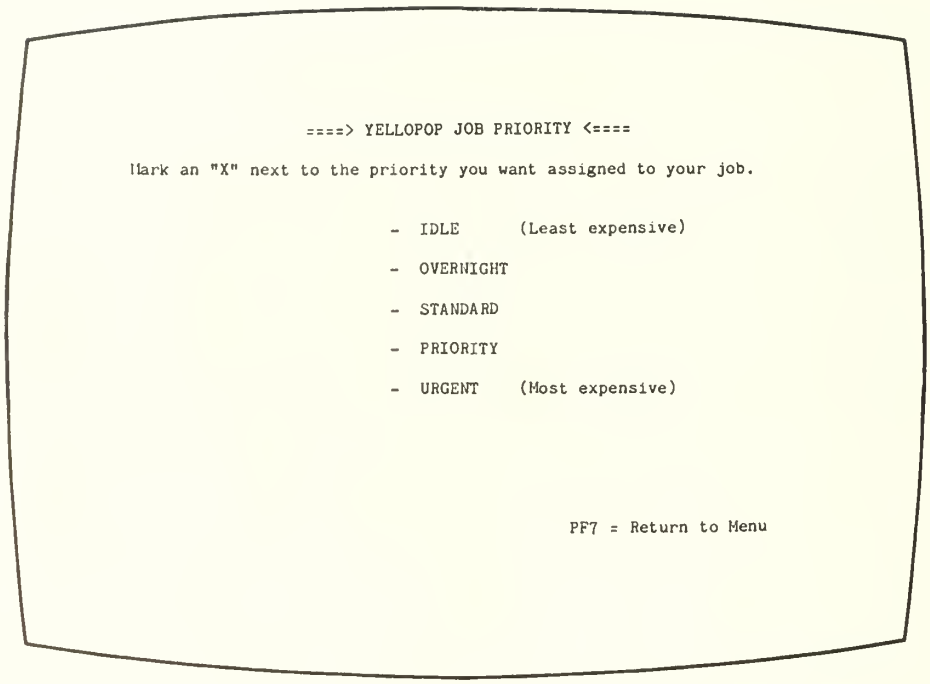

====> YELLOPOP JOB PRIORITY <====
Mark an "X" next to the priority you want assigned to your job.
- IDLE (Least expensive)
- OVERNIGHT
- STANDARD
- PRIORITY
- URGENT (Most expensive)
PF7 = Return to Menu

Figure 11.—YELLOPOP job priority.

Literature Cited

Gilmore, Robert C.; Hanover, Stephen J.; Danielson, Jeanne D. **Dimension yields from yellow-poplar lumber.** Gen. Tech. Rep. FPL–41. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory; 1984. 13 p.

Martens, David G. **Reduce dimension costs by using WALNUT.** Res. Pap. NE–586. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1986. 10 p.

Martens, David G.; Nevel Robert L., Jr. **OPTIGRAMI: optimum lumber grade mix program for hardwood dimension parts.** Res. Pap. NE–563. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1985. 10 p.

Appendix

Table 1.—Predicted yields of random-width, clear 2-face cuttings from FAS grade yellow-poplar lumber (net board feet per M bf)

Length of subsequent cuttings (inches)	Length of longest cuttings									
	10	20	30	40	50	60	70	80	90	96
	Inches									
96										359
90									400	405
80								444	482	485
70							460	508	533	538
60						475	526	563	581	582
50					520	540	581	607	617	620
40				580	591	613	621	640	649	651
30			630	642	650	658	668	675	678	679
20		680	690	695	698	703	710	712	714	713
10	775	750	745	745	748	750	753	753	754	753

Table 2.—Reduction values for obtaining predicted yields for cuttings of specified widths from FAS grade yellow-poplar lumber (net board feet per M bf)

Width of cuttings (inches)	Length of cuttings									
	10	20	30	40	50	60	70	80	90	96
	Inches									
2	59	52	47	42	38	35	32	27	22	20
3	110	101	93	86	79	74	68	60	51	47
4	168	155	144	135	127	120	112	97	91	83
5	228	215	202	191	182	175	167	155	144	130
5-1/2	259	248	235	223	213	206	198	185	174	158

Table 3.—Predicted yields of random-width, clear 2-face cuttings from F1F grade yellow-poplar lumber (net board feet per M bf)

Length of subsequent cuttings (inches)	Length of longest cuttings									
	10	20	30	40	50	60	70	80	90	96
	Inches									
96										240
90									240	270
80								260	305	325
70							280	335	465	385
60						325	365	400	425	440
50					370	415	440	460	480	495
40				425	460	485	500	515	530	545
30			490	515	530	545	550	560	580	595
20		575	590	580	585	600	595	600	620	635
10	730	670	660	635	630	640	625	635	655	670

Table 4.—Reduction values for obtaining predicted yields for cuttings of specified widths from F1F grade yellow-poplar lumber (net board feet per M bf)

Width of cuttings (inches)	Length of cuttings									
	10	20	30	40	50	60	70	80	90	96
	Inches									
2	58	49	41	35	30	25	22	19	15	12
3	120	108	93	80	70	63	57	48	38	34
4	191	175	156	140	128	115	101	85	69	65
5	272	253	231	213	197	178	158	135	109	102
5-1/2	316	298	275	255	236	214	190	162	131	122

Table 5.—Predicted yields of random-width, clear 2-face cuttings from grade 1C yellow-poplar lumber (net board feet per M bf)

Length of subsequent cuttings (inches)	Length of longest cuttings							
	10	20	30	40	50	60	70	80
	Inches							
80								225
70							235	300
60						265	320	365
50					315	355	395	430
40				350	390	430	460	485
30			435	445	465	495	515	535
20		545	530	520	535	555	570	580
10	690	640	610	575	580	605	615	630

Table 6.—Reduction values for obtaining predicted yields for cuttings of specified widths from grade 1C yellow-poplar lumber (net board feet per M bf)

Width of cuttings (inches)	Length of cuttings							
	10	20	30	40	50	60	70	80
	Inches							
2	48	40	33	29	25	20	16	11
3	120	105	90	80	70	60	48	38
4	220	198	173	154	135	118	96	78
5	351	320	284	250	221	193	158	133
5-1/2	429	390	349	310	274	238	199	168

Table 7.—Predicted yields of random-width, clear 2-face cuttings from grade 2A yellow-poplar lumber (net board feet per M bf)

Length of subsequent cuttings (inches)	Length of longest cuttings			
	10	20	30	40
	Inches			
40				250
30			290	360
20		425	400	460
10	630	530	480	525

Table 8.—Reduction values for obtaining predicted yields for cuttings of specified widths from grade 2A yellow-poplar lumber (net board feet M bf)

Width of cuttings (inches)	Length of cuttings			
	10	20	30	40
	Inches			
2	55	43	32	28
3	129	105	82	68
4	219	182	147	118
5	328	278	222	175
5-1/2	388	330	267	209

Table 9.—Predicted yields of random-width, sound 2-face cuttings from grade 2B yellow-poplar lumber (net board feet per M bf)

Length of subsequent cuttings (inches)	Length of longest cuttings			
	10	20	30	40
	Inches			
40				200
30			265	285
20		380	375	375
10	605	500	470	450

Table 10.—Reduction values for obtaining predicted yields for cuttings of specified widths from grade 2B yellow-poplar lumber (net board feet per M bf)

Width of cuttings (inches)	Length of cuttings			
	10	20	30	40
	Inches			
2	60	44	32	29
3	132	100	78	62
4	220	175	131	105
5	324	260	198	150
5-1/2	380	307	235	172

Martens, David G. **Produce yellow-poplar furniture dimension at minimum cost by using YELLOPOP.** NE–RP–592. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1986. 15p.

Describes a computer program called YELLOPOP that determines the least-cost combination of lumber grades required to produce a given cutting order of furniture dimension parts. If the least-cost mix is not available, YELLOPOP can be used to determine the next best alternative. The steps involved in using the program are also described.

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Keywords: Furniture, hardwood dimension; lumber yields; dimension yields

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NE-RP-593

Communicating with Nonindustrial Private Forest-land Owners: Getting Programs on Target

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MAR 27 1987

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Abstract

Nonindustrial private forest-land (NIPF) owners can be motivated by programs directed to their needs and objectives. Seven target audiences in Pennsylvania were defined and outlets for information programs identified for each target audience. The primary objectives of each group and the benefits they expect from owning forest land were considered in the preparation of each group's program. This system is now being used by Pennsylvania State University in its forest extension program.

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Nonindustrial private forest-land owners

Throughout the United States, private forest-land owners make management decisions affecting nearly 72 percent of the nation's timberland (USDA Forest Service 1981). A diverse group of 7.8 million individuals, corporations, groups and associations control these private forest lands (Birch et al. 1982).

Much has been written about this ownership group and recent surveys of nonindustrial private forest (NIPF) land owners have sought to determine what should be done about the "problem," which many perceive to be the lack of active management and resulting low productivity on the millions of acres of privately owned forest land. Although its low productivity has been questioned (Clawson 1979), the existence of NIPF land can be looked on as an opportunity. There is a large forest resource base which we, as professionals, have an opportunity to influence. Public foresters in most states are deluged with requests for assistance, many of which may go unanswered because there are not enough trained personnel to respond to them. An organized educational program could provide much of the information these landowners want-- information currently distributed through one-to-one contacts.

Worrell and Irland (1975) discuss both public and private goals and motivations, concluding that programs aimed at motivating private forestry in the United States have had "less than spectacular" success, because incorrect agencies were chosen to conduct programs or programs were aimed inaccurately. They point out that many efforts have been aimed at landowners whose reasons for not practicing management are such that motivating them is impossible. One promising approach in formulating educational programs is to identify target audiences and direct programs to their needs. Kurtz and Lewis (1981) identified four such groups in the Missouri Ozarks. Three target groups were identified by similar techniques in Wisconsin (Marty 1983). Though interest categories may or may not be identical in other regions, the results of their studies illuminate one salient fact: "Motivations are guiding forces and knowing what they are should be the starting point for any effort to stimulate productivity."

In Pennsylvania, 78 percent (12.5 million acres) of the commercial forest land is in private ownership (Powell and Considine 1982). Though it may, in fact, be impossible to motivate some of the 490,100 forest-land owners in Pennsylvania, Birch and Dennis (1980) indicate that a number of identifiable landowner groups could be reached effectively. By analyzing the characteristics of these groups, especially their reasons for owning forest land and harvesting or not harvesting timber from it, a motivational plan targeted specifically at each group may be developed.

The objective of this paper is to provide information useful in formulating and targeting educational programming for nonindustrial private forest landowners. Some of these suggestions have been tried in different states with various degrees of success. The authors have modified particular approaches when they failed to generate the desired result. Some have not been tried, but are based upon characteristics of land owners and motivational theory. The characteristics of groups identified in this paper were estimated from the forest-land owner study conducted by the USDA Forest Service's Northeastern Forest Experiment Station and the analysis done in cooperation with Pennsylvania State University.

The survey

The 1977 Pennsylvania landowner survey generated data on a variety of topics, including size and location of ownership, tenure, size of trees, and past harvest experience. Two basic areas, (1) ownership characteristics, objectives, and attitudes, and (2) facts

concerning harvest and utilization of forest products, have been further analyzed in an attempt to target extension and service forestry programs.

Table 1: Topics analyzed in the 1977 Pennsylvania landowner survey

Ownership characteristics, objectives, and attitudes	Harvest and utilization of forest products
Size of ownership	Past history of harvesting
Occupation	Individual selecting timber
Reasons for owning	Method of harvest
Primary benefits expected	Product combinations harvested
Magazines subscribed to	
Reasons for harvesting and not harvesting	
Intention to harvest in future	

Eleven topics (Table 1) were analyzed for eight NIPF owner groups (Fig. 1) within Pennsylvania. Since size of ownership has a decided influence on willingness and ability to manage forestland economically (Kessler 1978, Thompson and Jones 1981, Row 1978), acreage of ownership was selected as a primary characteristic of each ownership group. Past studies (Marler and Graves 1974, Webster and Stoltenberg 1959) have also indicated that farm and nonfarm owners may have substantially different objectives and motivations for forest management.

Survey data on topics listed in Table 1 were combined with data in Figure 1 to create ownership profiles that included the two or three most common responses to survey questions within each group. Data presented are for the state as a whole unless otherwise indicated. Summaries of data were also compiled by regions to permit more specific targeting of programs on a regional basis within Pennsylvania.

Survey results

The survey indicated that, in Pennsylvania, forest land is owned for the following reasons (in descending order of preference by acres owned): (1) recreation, (2) investment, (3) part of farm, (4) farm and domestic use, (5) other (includes: oil, gas, or mineral extraction and watershed protection), (6) aesthetics, (7) part of residence, (8) timber production.

Farm and nonfarm groups differed significantly in their primary reasons for owning forest land (Fig. 2). Farmers were more likely to indicate "farm and domestic use" and "part of

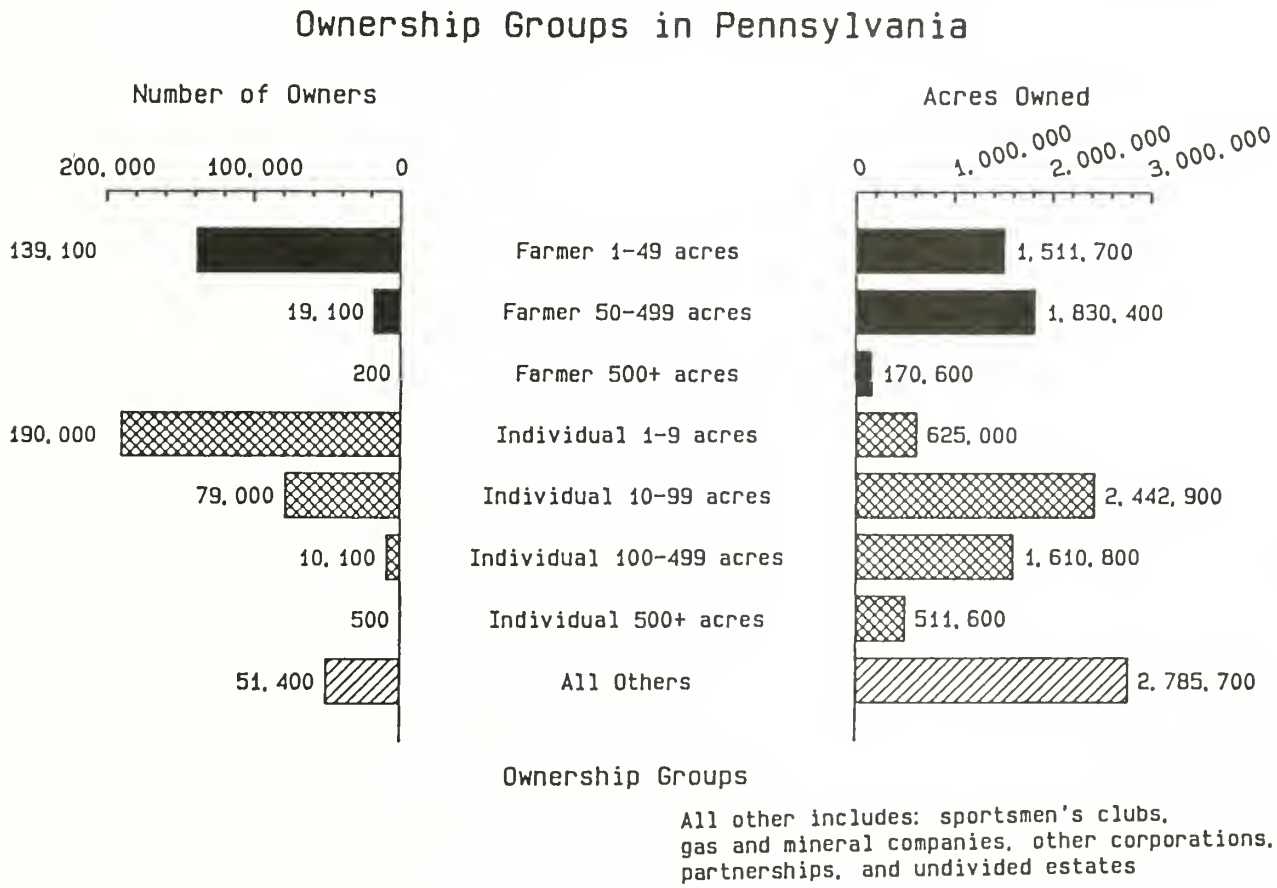

Figure 1.--Distribution of private ownership groups in Pennsylvania.

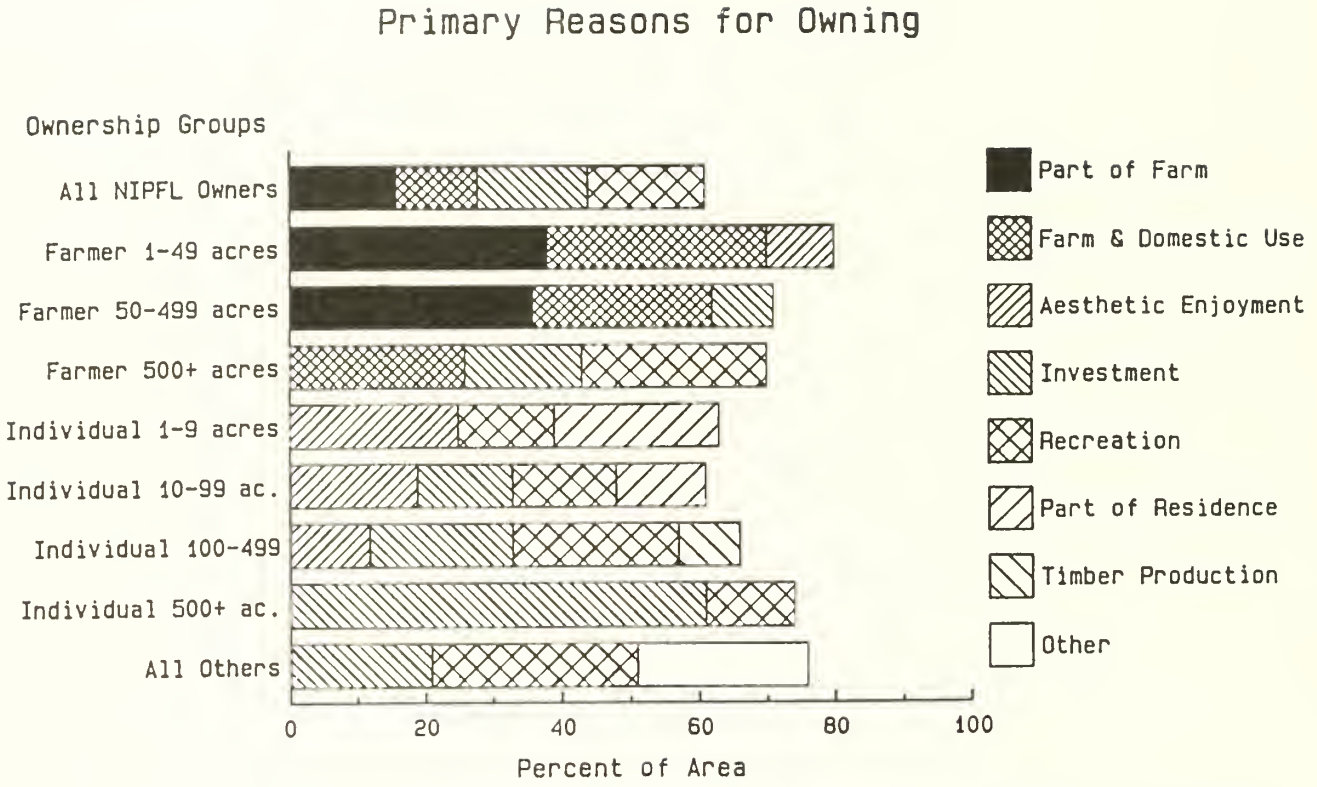

Figure 2.--Distribution of private ownership groups, by primary reason for owning forest land.

farm" as primary reasons. With the exception of ownerships less than 100 acres, nonfarm owners listed recreation and investment most often as primary reasons for forest ownership. Nonfarm individuals with less than 100 acres gave aesthetic enjoyment as their primary reason for owning forest land.

Benefits expected from forest land ownership show similar patterns (Fig.3), indicating that motivation for ownership of 24 percent of the state's forest land is involved with investment, 21 percent with aesthetics, and 17 percent with recreation. Only 6 percent of Pennsylvania's nonindustrial private forestland is owned by people who expect income from timber to be their primary benefit in the next 5 years.

With such low concern for timber production, it may seem surprising that 73 percent of Pennsylvania's forest products are harvested from NIPF owners' property (Considine and Powell 1980). When motivation for harvesting or not harvesting timber is examined, it is apparent that economics play a major role in the decision to harvest. Landowners who hold forest land for recreational reasons, or simply because it is part of their farm, are likely to harvest if they need money or are offered a "good price." Binkley's observation (1979) that owners respond to high prices even if timber production is a low-priority objective appears to hold true in Pennsylvania. Small landowners are more likely to cut trees for their own use, while larger landowners tend to harvest when timber is mature, especially if motivated by a need for extra income.

Belief that harvesting timber will

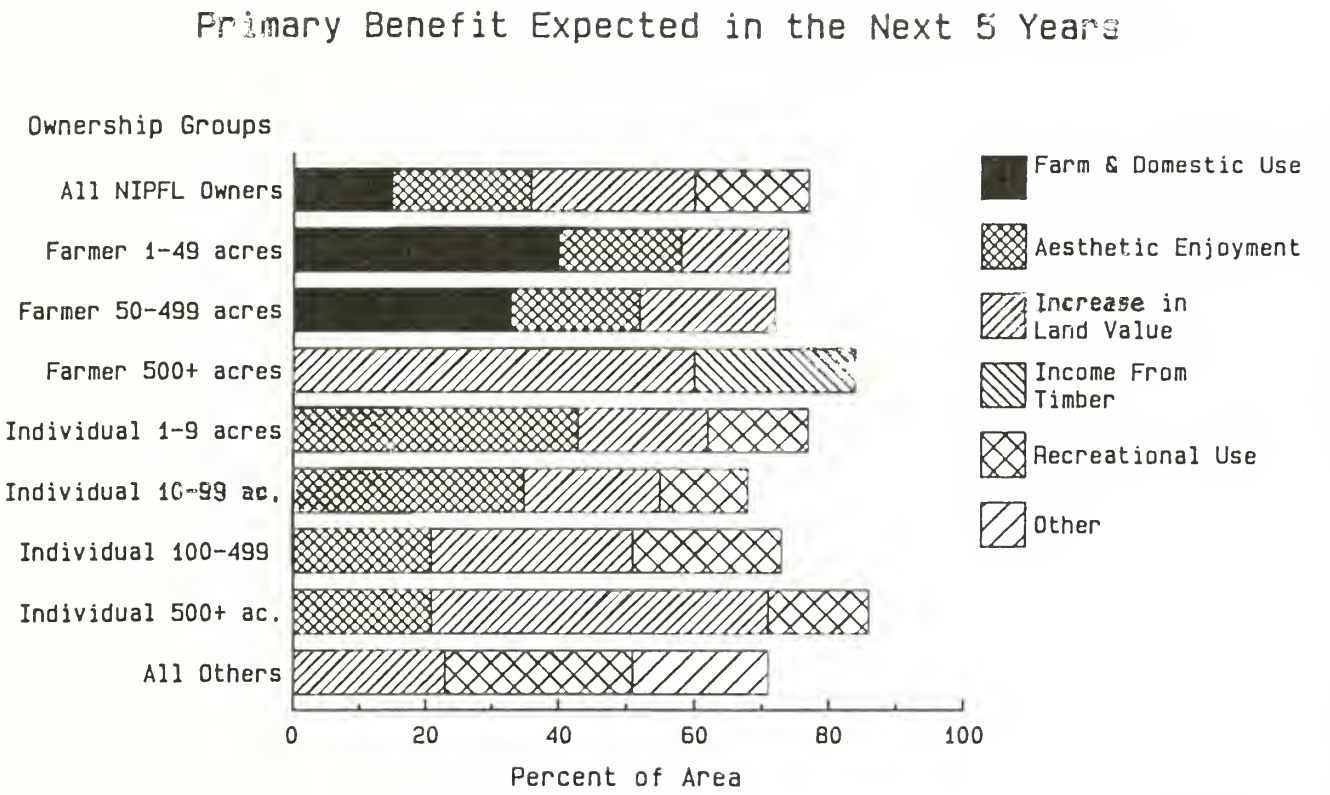

Figure 3.--Distribution of private ownership groups, by primary benefit expected in the next 5 years.

ruin the scenery in a woodland is a primary deterrent to harvesting forest products for many owners. As Pennsylvania's second-growth forests reach maturity in the near future, this belief seems to be the main motivating force preventing owners from harvesting.

Reasons for not harvesting may have far less impact on future timber supplies than reasons for harvesting. Turner et al. (1977) indicate that a landowner's stated intent to harvest or not harvest may alter in less than 5 years, especially if economic incentives are brought to bear. Survey data indicate that 28 percent of landowners who have harvested in the past plan never to harvest again. Of those who have never harvested, 56 percent indicate that they never will.

With the exception of very small ownerships (individuals; 1-9 acres), the majority of the acreage is controlled by landowners who expressed a willingness to harvest (Fig. 4). The 8 percent who plan to harvest within 10 years of the survey control 2,687,200 acres. The 34 percent whose harvesting plans are indefinite control 5,372,800 acres. When demand for timber increases, followed by increasing prices for forest products, research indicates that many NIPF owners will harvest as their trees reach maturity, despite expressed opposition to harvesting.

Targeting NIPF owners

We can use information provided by the landowner survey to motivate increased management. The question must be posed: management for what? Close to 2 million acres in the state are owned primarily for recreation.

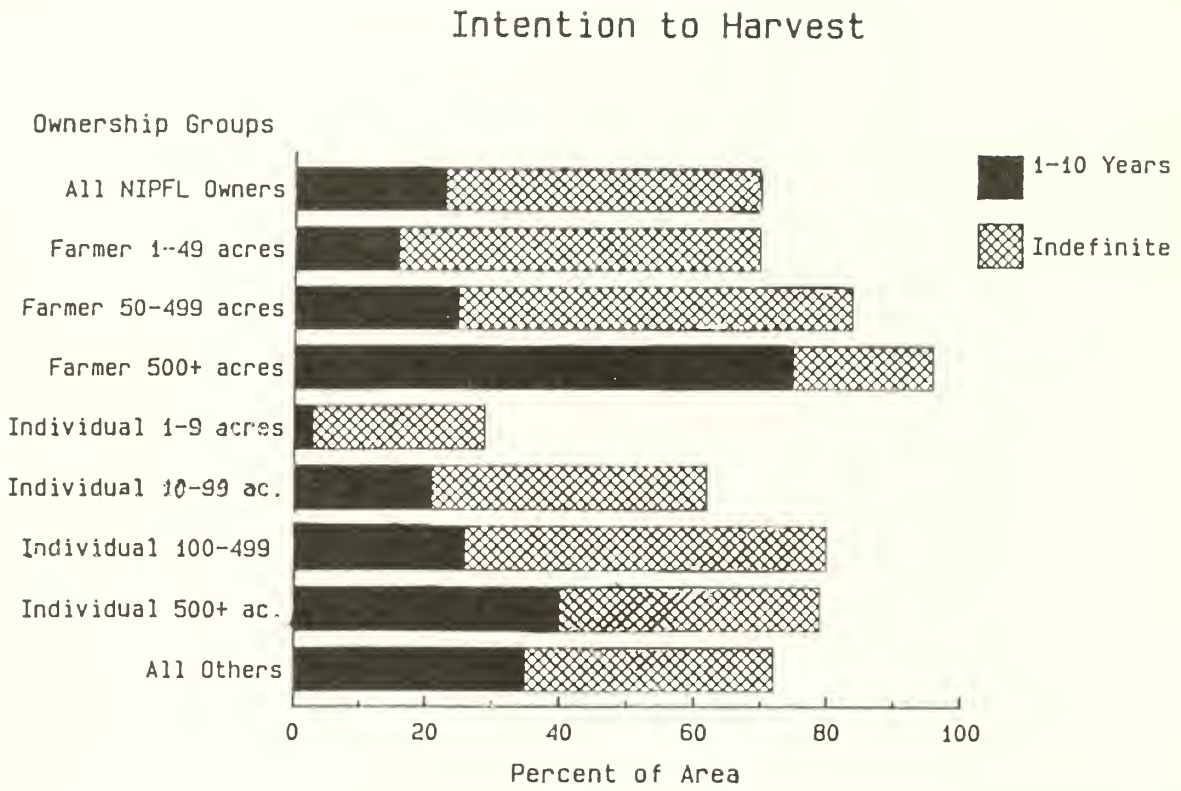

Figure 4.--Distribution of private ownership groups, by intention to harvest timber from their forest land.

Recreation includes hunting, camping, and fishing, as well as hiking and more passive recreation.

Management for wildlife and outdoor recreation requires a variety of silvicultural and management practices, which could include selection cuts, regeneration cuts, and thinnings. More than 1,800,000 acres owned for investment will increase in value under a management plan as well as providing added income from timber harvesting if the owners so desire. Undisturbed hardwood stands in Pennsylvania increased in value at a rate of 4.7 percent per year over the last decade (Herrick 1984).

The 1,767,400 acres that are parts of farms in Pennsylvania can provide added income and a sustained yield of fuelwood, lumber, and fenceposts under well-designed management. There is no owner objective specified in the survey that would not be more achievable under planned management. Our challenge is to inform and educate NIPF owners to see and accept the benefits of forest management.

An extension objective is to educate and inform NIPF owners to increase their practice of forest management. Who are we trying to educate and how should we go about it? Group profiles generated by analysis of survey data provide part of the picture. Retired people, farmers, executives, and professionals control 46 percent of Pennsylvania's forest land (5,291,100 acres). Retired people alone control more than 1,800,500 acres, with full-time farmers placing second (1,480,600 acres), executives third (1,167,800 acres) and professionals

fourth (842,200 acres).

Motivations and occupations help identify target groups. The 1977 survey queried landowners about membership in conservation organizations and subscriptions to conservation-oriented magazines. No single organization listed had more than 8 percent of all landowners as members. Owners of more than 60 percent of the state's private forestland belong to no such organization.

Magazines subscribed to presented a different picture. Approximately 25 percent of individual forest landowners receive Pennsylvania Game News. They own approximately 33 percent of the state's private forestland. The most widely read magazines included in the survey are: Pennsylvania Game News, Agway Cooperator, Field and Stream, Sports Afield, and National Wildlife.

We have identified the following target audiences and present programming ideas for each.

Target: People interested in wildlife

A major portion of Pennsylvania's wildlife resource is produced on NIPF lands. The way in which these lands are managed will directly affect how well the state's wildlife needs are satisfied. With this background in mind, several avenues for reaching large groups of landowners present themselves. Motivations, benefits expected, and magazines subscribed to make it clear that interest in wildlife is significant within the NIPF owner population. Therefore, slightly popularized articles on the benefits of forest management for wildlife should be placed in as many of the publications mentioned as possible. Programs on forest management for wildlife benefits delivered to sportsmen's clubs will also reach large numbers of NIPF owners.

Topics to be considered for reaching landowners with wildlife interests should include: silviculture systems (even-age vs. uneven-age management), basic forest ecology; dendrology (including identification of species that provide food and/or cover), integrated pest management, soil and water conservation, and multiple use management.

Target: Retirees

The retired people who control nearly 2 million acres of forest resources may be reached through local or state chapters of the American Assocation of Retired Persons (AARP) as well as through articles in Modern Maturity (a publication of the Association). Although this publication was not included in the survey, we believe that Modern Maturity is received in a significant number of NIPF owners' homes. The editors are reluctant to publish an article dealing strictly with forest management, but articles featuring seniors who are actively managing forest land may "sell". Similar "human interest" articles in the local press may raise awareness of forest resources. AARP conducts frequent tours, and may be interested in a well-organized forest management tour. Elderhostel, Inc., an international nonprofit organization that provides educational programs for older adults, is another avenue for reaching this group, with programs at colleges and universities throughout the country. An intensive short course on forest management offered at Penn State in the summer of 1984 attracted 20 forest landowners, with average holdings of approximately 80 acres. On course evaluations participants said they had "benefitted significantly" from the program. Although this course was not directed specifically at retirees, a majority of the participants were of or approaching retirement age. Forestry specialists need only develop forestry programs for presentation and offer them at a variety of times and locations convenient to retirees.

Retirees who are not interested in wildlife or general forestry topics may be motivated by programs and information on taxation and estate planning,

marketing forest products, and determining financial maturity of resources they control. Information on selecting and working with consulting foresters would also be of special value to this group.

Retirees have a substantial impact on forest management, as they hold close to 2 million acres of forest land in Pennsylvania. Other states may find similar patterns and chose to focus on this group as a priority audience. We may find retirees a rewarding group to begin with, as we will not be competing with their careers for their attention.

Target: Professionals and executives

Professional people and executives may be reached on the job through articles in such publications as the Wall Street Journal, and Business Week. Both have published articles and notes dealing with forestry in the past. Such articles, and presentations to business and professional clubs and fraternal organizations, should focus on economic benefits of management, forest taxation, and marketing. Many members of this group may also be reached during leisure time through avenues listed for wildlife-oriented landowners.

As women become increasingly involved in forest management as well as the business and professional world at large, magazines such as Working Woman should be considered for articles on forestry investments. Workshops for bankers, real estate brokers, CPAs, and tax assessors could also be of value in getting information on forestry into the hands of professionals and executives. Financial (tax, investments, marketing) aspects of forestry should be presented to this audience, and multiple use and basic forest ecology would probably be of interest as well.

Target: Farmers

Farmers should be informed about basic techniques of fuelwood management, benefits of multiple-use management, marketing procedures, erosion and sedimentation control, forest taxation, and forestry consultants. Information on tree farming might be particularly pertinent to this group. Avenues for information exchange appropriate to reaching this group include articles in Agway Cooperator, Pennsylvania Farmer, Pennsylvania Game News, and Field and Stream. County Extension programs and newsletters provide outlets for educational efforts. Conservation district newsletters should not be overlooked. Agricultural fairs and events such as "Ag Progress Day" and the annual Farm Show are appropriate for displays and dissemination of information.

Target: Middle size ownerships

Programming aimed at owners of tracts between 10 and 499 acres will be the most cost-efficient, as these people control more than half of Pennsylvania NIPF resources. The group "all others" controls 2,785,700 acres. Programming directed toward this group through sportsmen's clubs, corporate newsletters, or other channels could be extremely cost-effective.

Personnel of the Pennsylvania Division of Forestry have reported enthusiasm from snowmobile club members introduced to forestry concepts through slide-tape presentations generated by extension personnel. Program materials geared for such audiences would be useful.

Target: Small ownerships

The 309,900 owners (63 pecent), with fewer than 10 acres of forest land, control 1,028,000 acres of forest land (8 percent of the private timberland). It is probably not cost-effective to work with this group at present, but if landowner associations become more widespread, this group may become more influential. Organized groups of small landowners could provide a forum for information exchange as well as forming a nucleus for political action. Associations can improve the marketing picture by

aggregating sufficient timber to achieve economies of scale, and may hire consultants to assist association members in management planning.

The most cost-efficient way to serve the small ownership audience at present is through newsletters. Every NIPF landowner contacted should appear on a mailing list to receive information regularly. Frequency of stimulation (in this case reading information about forest management) affects motivational impact. Displays, newsletters, or newspaper articles every month could make programs more effective (Korman 1974).

Target: All NIPF owners

Essential needs bring people to certain locations, regardless of age, occupation, or interests. Shopping centers, libraries, schools, and county buildings serve thousands of people daily. Displays on general forestry topics and lists of sources of information set up in such facilities would be visible to virtually any NIPF owner. Local newspapers should be considered, perhaps for syndicated articles.

Programming for the general public can be varied. Topics of interest may include: forest-wildlife interactions, products that forests provide, basic tree identification, pruning and insect control, multiple benefits of our forestland, forests as watersheds, forests as recreation spots, forests as an investment. Home economics extension newsletters reach hundreds of homes monthly.

Youth education could also be a focus for foresters. Ranger Rick Magazine reaches the homes of a substantial number of NIPF landowners. The use of 4-H as a vehicle for introducing new techniques to farmers through their children can work in forestry as it has with more traditional agriculture practices in the past. School programs, Future Farmers of America, and Scouts provide additional pre-organized audiences. The authors have met many whose interest in forestry began through such youth programs. As SAF members we should all be promoting and supporting the use of Project Learning Tree in our local school systems.

Pennsylvania is not alone

In the northern United States in 1970 more than 128.4 million acres of timberland (25.7 percent of the regional total) were owned by "farm and miscellaneous private" individuals--basically the NIPF owners described above (Marler and Graves 1974). On a national level, 296.2 million acres or 59 percent of the timberland was controlled by this group. It is projected that this group will continue to own well over 50 percent of the nation's commercial timberland through the year 2020.

Marion Clawson, in The Economics of U.S. Non-industrial Private Forests (1979), pointed out that NIPF owners produce a variety of outputs in addition to wood. Recognizing the social and economic values of these outputs, Clawson notes that "in the long run nearly all truly merchantable timber from such forests will be sold and harvested in regions where good markets exist, although the timing of such sales might be irregular and not what a forester would have recommended."

Conclusion

By encouraging management for multiple use on NIPF properties, we may not only increase their nontimber outputs, but timber outputs as well. Regionally and nationally, the motivations for forestland ownership must be examined, and programs directed toward identified audiences. Increased awareness of the benefits of forest management for wildlife, recreation, and investment, as well as timber, will motivate increased management. While poor markets, diseconomies of scale, unfavorable tax situations, and lack of knowledge will continue to serve as

disincentives to management, nothing will be more effective in improving management than accurately targeted educational programs on topics in which NIPF owners have an interest. Awareness can spur interest and action to overcome many disincentives. The Task Force on Programs to Improve Outputs from Nonindustrial Private Forests (1979) reported that "...enlightened self-interest is the most powerful and effective force in bettering forest management in the long run."

If we can make NIPF owners aware of the genuine benefits of forestland management, they will find ways--with or without federal programs--to improve their forest resources and supply multiple benefits for present and future generations. The approach outlined in the current SAF position on improving outputs from these lands is a step in the right direction.

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Keywords: Forestry assistance, recreation, forest-land ownership, available timber, harvesting

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NE-RP-594

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Effects of a Prescribed Fire in a Central Appalachian Oak-Hickory Stand

G. W. Wendel
H. Clay Smith

Abstract

Five years after a single prescribed fire in a second-growth central Appalachian oak-hickory stand, many overstory trees died or declined in vigor. A major reduction in butt-log quality on the residual trees was observed. Fire scars were prevalent on a large number of trees and scars showed various stages of decay. Advanced seedling and sprout reproduction increased for red maple, northern red oak, and hickory. Overall stocking of advance reproduction of red maple, black locust, and hickory increased during the 5 years; red and chestnut oak were poorly distributed and accounted for only 3 percent of the stocking. Striped maple was the most abundant and widespread noncommercial species before and after burning. The large amount of damage to the overstory stand and failure to control the large number of noncommercial understory stems with a single prescribed fire indicate that more research is needed before fire can be recommended for use as a regeneration tool in central Appalachian hardwood stands.

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Introduction

It is difficult to maintain a component of northern red oak (*Quercus rubra* L.) in regenerating Appalachian hardwood stands. This problem is more acute on high-quality sites where fast-growing species such as yellow-poplar (*Liriodendron tulipifera* L.) often dominate after clearcutting. Past research indicates that advance reproduction of large oak (more than 4.5 feet tall) is essential in maintaining an oak component in the new stand after overstory removal (Sander 1972). Loftis (1979) suggested shelterwood cutting with control of understory vegetation as one way to promote large oak advance reproduction.

Fire in hardwood forests has long been shown to be beneficial for improving the wildlife habitat, but the silvicultural benefits of fire are uncertain—particularly with regard to oaks. Prescribed fires in southern hardwood forests have increased browse and total herbaceous and vine coverage (Huntley and McGee 1982; Loomis 1977). In West Virginia hardwood forests, experimental fires resulted in increases in herbaceous vegetation and a more open understory structure which appeared to favor young turkey and grouse (Rogers 1984). However, the beneficial effect of burning for habitat and improvement begins to decline in the third year, indicating that frequent intervals of burning may be required to maintain the desired habitat.

In this paper we compare stand conditions before and 5 years after a fire to improve wildlife habitat that was carried out by the West Virginia Department of Natural Resources on the Road Run drainage of the George Washington National Forest near Brandywine, West Virginia.

The Study

The study area consists of 21 acres and was burned in the spring of 1980 (Fig. 1). Four adjacent acres were not burned and provide a basis for comparison.

Stand Condition

Before burning, the stand contained 115 trees per acre larger than 5 inches in diameter at breast height (d.b.h.). Red maple (*Acer rubrum* L.), chestnut oak (*Q. prinus* L.), red oak, hickory (*Carya* sp.), and black locust (*Robinia pseudoacacia* L.) were the major species (Table 1). On an adjacent unburned area there were 87 trees per acre larger than 5 inches in d.b.h. Chestnut oak, hickory, red maple, and red oak were the most abundant species. Basal area on the burned area before treatment was 90 ft^2 per acre and 90 ft^2 per acre on the unburned area (Table 2). Volume in trees larger than 11 inches in d.b.h. on the burned area was about 8,300 board feet per acre and about 12,000 board feet per acre on the unburned area. Effects of the fire were evaluated on the overstory trees (Table 3). A year before the area was burned, most of the unmerchantable trees 2.0 to 6.0 inches in d.b.h. plus a few of the larger cull trees were felled on the burned area. Although some of the stand parameters differ between the two areas, species composition, topography, and climate are similar. The understory advance reproduction on the burned area consisted of seedling- and sprout-origin red maple, chestnut oak, red oak, black locust, and hickory (Table 4). Understory advance reproduction on the unburned area was similar except that no black locust was present (Table 4). Both areas had heavy understory concentrations of striped maple (*A. pensylvanicum* L.), dogwood (*Cornus florida* L.), and witch-hazel (*Hamamelis virginiana* L.).

Table 1.—Species composition as percent of total number of trees more than 5.0 inches in d.b.h. on burned and adjacent unburned areas before and 5 years after burning

Species	Burned area		Unburned area	
	1980	1984	1980	1984
	Percent			
Red maple	31	26	12	21
Chestnut oak	22	23	54	45
Red oak	18	21	8	14
Hickory	10	14	15	7
Black locust	9	7	0	7
Other	10	9	12	7

Table 2.—Per-acre stand data before and 5 years after the fire

Year	No. stems[a]	Basal area (ft^2)	Volume: Cubic feet	Volume: Board feet[b]
	Per acre			
	BURNED AREA			
1980	115	90	1,979	8,347
1984	93	73	1,596	6,541
	UNBURNED AREA			
1980	87	90	2,249	12,025
1984	96	96	2,391	12,711

[a]5.0 inches in d.b.h. and larger.
[b]11.0 inches in d.b.h. and larger.

Figure 1.—General view of the fire.

Table 3.—Severity of decay observed in overstory fire-scarred trees after 5 years

Species	Decay class[a]		
	1	2	3
	Percent		
Red maple	10	28	62
Blak gum	29	0	71
Black oak	67	0	33
Red oak	13	22	65
Chestnut oak	34	6	60
Hickory	31	8	61
Black locust	27	40	33
All species	22	17	61

[a]1 = Incipient decay: discoloration no fruiting bodies present; 2 = Moderate: few fruiting bodies, discoloration small amount of punky wood; 3 = Heavy: many fruiting bodies, associated with soft punky wood.

Soils and Climate

The study area is a shallow cove with associated ridges and slopes of 25 to 30 percent. Soil is classified as Berks-Rushtown-Weickert Association. Precipitation averages about 40 inches annually, and the growing season is about 150 days from about mid-April to early October.

Vegetation Sampling

Thirty-eight sampling points on a 1- by 2-chain grid were established on the burned area, and seven sampling points were established on the unburned area. Overstory trees larger than 5 inches in d.b.h. were tallied on 1/10-acre plots at odd-numbered sampling points. Large reproduction, trees 1.0 to 4.9 inches in d.b.h., were tallied on 1/100-acre plots at each sampling point. Trees were measured to the nearest 0.1 inch and tallied by species, stem quality, crown class, and whether they were of seedling or sprout origin. Overstory trees were evaluated for fire damage at the end of 5 years. Advance reproduction, 1.0 foot high to 0.99 inch in d.b.h., was tallied on a milacre plot at each sampling point.

Fuel Sampling

Forest fuels included the forest litter down to the beginning of the humus layer and all dead twigs, branches, and living vegetation smaller than 1.0 inch in d.b.h. Fuels were designated as woody or litter and were kept separate for determining the combined fuel weight. Fuels were sampled on predetermined 1/4-milacre square plots adjacent to odd-numbered sampling points before burning and adjacent to even-numbered sampling points after burning. The two fuel components were subsampled and weighed separately to determine moisture content so that oven-dry weight per acre for each component and the total could be determined.

Fire Behavior

Weather in the fire area was monitored before and during the fire. Wet- and dry-bulb temperatures, wind speed and direction, rates of fire spread, and flame heights were recorded during the fire when sustained changes in these parameters were observed. Flame heights and rates of spread were not recorded for flare-ups of relatively short duration. A small test fire was ignited to indicate the intensity of fire that could be expected.

Fireline intensity was calculated by the following method (Davis 1959):

$$I = Hwr$$

where

I = fire intensity in Btu/foot-second of fire line,

H = heat yield in Btu/pound of fuel (used 6,500 Btu/lb),

w = weight of available fuel (amount of fuel actually consumed by the fire) in lb/ft^2, and

r = rate of fire spread in feet/second.

Burning Procedures

The main fire was started at 2:30 p.m. on April 21, 1980. The relative humidity was about 25 percent and winds were 3 to 5 m.p.h. from the northwest. Relative humidity remained at 25 percent for the first hour and increased slowly to 42 percent at 4 p.m. It ranged from 42 to 48 percent until burning was completed at 5 p.m. Wind remained from the northwest during the afternoon but became more brisk with gusts to 12 m.p.h.

The main downwind firelines were fired first. After the backfire had burned in 30 to 40 feet, the upper two-thirds of the area was strip-fired parallel to the backfired lines at intervals of about 20 feet. Firing continued along the perimeter so that the strip head fires always burned out in a burned area inside of the perimeter. After all of the perimeter had been fired, the lower one-third of the area was fired. Total elapsed time for the fire was about 2-1/2 hours. Except for a small breakover, the fire was carried out according to plan.

Table 4.—Advance reproduction 1.0 foot tall to 0.9 inch in d.b.h. before and 5 years after burning.

Species	Time	Seedlings per acre	Sprouts per acre	Total	Stocking
		Number			*Percent*
		COMMERCIAL			
Red maple	Before burn	132	1,368	1,500	21
	After 5 years	368	1,395	1,763	50
Chestnut oak	Before burn	26	947	973	8
	After 5 years	0	316	316	5
Red oak	Before burn	0	658	658	3
	After 5 years	26	0	26	3
Black locust	Before burn	526	0	526	21
	After 5 years	500	658	1,158	58
Hickory	Before burn	0	0	0	0
	After 5 years	79	79	158	11
Other	Before burn	157	0	157	13
	After 5 years	79	0	79	13
Total	Before burn	841	2,973	3,814	47
	After 5 years	1,052	2,448	3,500	82
		NONCOMMERCIAL			
Striped maple	Before burn	3,921	342	4,263	76
	After 5 years	2,158	1,658	3,816	66
Dogwood	Before burn	605	1,158	1,763	26
	After 5 years	737	1,553	2,290	34
Witch-hazel	Before burn	290	395	685	16
	After 5 years	365	184	552	34
Other	Before burn	52	316	368	11
	After 5 years	184	0	184	11
Total	Before burn	4,868	2,211	7,079	84
	After 5 years	3,444	3,395	6,839	89

Fire Behavior

During the early phase of the fire when relatively narrow strip head fires were used, the rate of fire spread averaged about 2 feet per minute. Higher rates of spread, 3 to 35 feet per minute, were observed in deeper hollows on associated steep slopes where there was a heavy accumulation of litter and other fuels. Later in the day, winds became more gusty, further influencing the rate of spread.

Fuel consumption was variable. Before the fire, litter fuel averaged 4.39 $\pm$0.74 tons of oven-dried material per acre, and woody fuel was estimated at 12.6 $\pm$6.33 tons per acre. Sampling after the fire showed that litter fuel averaged 1.93 $\pm$0.46 tons of oven-dried material per acre, and woody fuel averaged 10.36 $\pm$6.39 tons of oven-dried material. The fire consumed about 56 percent of the litter fuel and 18 percent of the woody fuel. Combined, about 28 percent of the total oven-dried fuel was consumed. Small twigs less than 1.0 inch in d.b.h. were consumed over the area. Consumption of larger material was spotty except in areas where it was concentrated and in areas where fire intensity was highest.

Fireline intensity ranged from 47 to 425 Btu per foot-second of fireline. In general, the lower fire intensities were associated with the narrower strip head fires. As the perimeter of "safe" area increased, wider strips were used; this in combination with heavier fuel loading in the hollows contributed to an increase in fire intensity.

Results

Effects on Overstory Vegetation

During the 5 years after the fire, 22 trees per acre larger than 5 inches in d.b.h. died on the burned area compared to a net gain of 9 trees per acre on an adjacent unburned area (Table 2). Similarly, basal area decreased by 17 ft^2 per acre on the burned area compared to an increase of 6 ft^2 per acre on the unburned area. There also were decreases in cubic- and board-foot volumes on the burned area.

Sixty-six percent of the overstory trees in the burned area were damaged by the fire; 5 percent were killed; 28 percent showed no damage; and 1 percent died from other causes. The length of fire scars ranged from less than 1 foot to more than 30 feet and averaged 5.3 $\pm$ 0.9 feet on all damaged trees. After 5 years, the area of exposed wood on scarred trees ranged from 25 in^2 to 2,900 in^2 and averaged 651 $\pm$ 154 in^2 per tree for all species. Length of scar and area of scar were not correlated with tree d.b.h. In most cases, callous tissue along the edge of scars was well formed. Heavy decay—large numbers of conks and punky soft wood—was observed on 61 percent of the scarred trees; 17 percent were classed as having moderate decay and 22 percent were classed as having incipient decay—discoloration mostly with none or very few conks (Fig. 2). By species, black oak and black locust had the lowest incidence of heavy decay (Table 3).

Saplings

Most of the trees in the 1.0- to 4.9-inch class on the burned area were cut 2 years before burning, leaving an average of 37 red maple and hickory saplings per acre. There were 34 red maple and 3 hickories per acre with a milacre stocking of 21 and 3 percent, respectively. Hickory was sparse. Five years after the fire, the sapling stand contained 3 red maple and 82 black locust sprout-origin stems per acre. The hickories were killed. Stocking of black locust was 32 percent. Of the 37 noncommercial 1.0- to 4.9-inch stems per acre present before the fire, only 3 striped maple sprouts were present 5 years later.

By contrast, sapling stems on an adjacent unburned area increased from 128 to 186 stems per acre during the 5 years. Noncommercial species, dogwood, striped maple, and witch-hazel, increased from 43 to 158 stems per acre.

Advance Reproduction

Before burning, advance reproduction 1.0 foot high to 0.9 inch in d.b.h. totaled 3,814 stems per acre; 5 years after the fire there were 3,500 stems per acre (Table 4). Seedling-origin stems increased by 211 per acre and sprout-origin stems decreased by more than 500 per acre.

Figure 2.—Example of tree wounding from the prescribed burn and fruiting bodies of decay organisms.

A tally made 3 years after the fire showed that chestnut oak seedling-origin stems had increased from 26 to 53 per acre, but all died before the 5-year tally was taken. No red oak seedlings were recorded before the fire but 3 years later there were 53 per acre; at the end of 5 years, one-half of these were dead. There was a surge in the number of black locust seedlings during the first 3 years after the fire. However, three-fourths or about 1,500 of these seedlings died by the time the 5-year measurement was made.

Sprout stems less than 0.9 inch in d.b.h. totaled 2,973 per acre before burning and 2,448 per acre after 5 years. Red maple was the most common sprout and changed little in number during the 5 years after burning. There were no black locust sprouts before the fire but there were 658 stems per acre 5 years later. Basswood (*Tilia americana* L.), white pine (*Pinus strobus* L.), sweet birch (*Betula lenta* L.), and black gum (*Nyssa sylvatica* Marsh.) seedlings that were observed before the fire or 3 years later were dead 5 years after the burn.

Seedlings of noncommercial species totaled about 7,000 stems per acre before and 5 years after burning. Striped maple seedlings and sprouts dominated with 4,263 stems per acre and 76 percent milacre stocking before the fire. Five years after the fire, there were 3,816 striped maple stems per acre and 66 percent of the plots were stocked with at least 1 stem. Dogwood and witch-hazel seedlings and sprouts accounted for 2,843 stems per acre and 34 percent stocking 5 years after the fire.

On the unburned area, the number of commerical species of seedlings and sprouts increased over the 5-year period (Table 5). Red oak and chestnut oak seedlings increased both in numbers and distribution, indicating that some acorns had been produced and had germinated during the 5-year period. The increase was greatest during the first 3 years. A similar response on the burned area suggests that the surge and decline of oak on the burned area was not fire related. The numbers and distribution of noncommerical species on the unburned area also increased during the 5-year period.

Management Implications

Compared to the unburned area, we expected the burned area to have at least the same number or more seedlings, but this did not occur. We assume that a fair to good acorn crop occurred in the general area during the 5-year period because of the increase of red oak and chestnut oak seedlings on the unburned area. Milacre stocking is adequate on the burned area for species other than oak. Red maple and black locust dominate the advance reproduction and would be major components in the new stand if the overstory were removed in the near future.

Burning for regeneration of oak on Road Run has not enhanced the establishment of oak. It appears that we have a much better chance of establishing oak if we do nothing, as has been shown on the adjacent unburned area. On oak site indexes 70 and below, oak seedlings seem to become established and will survive for a number of years until they are released. Established oaks are regarded as more fire resistant, mainly because of their sprouting ability. Also, light fires when the seedlings are 5 to 10 years old might kill some of the shrubs and less desirable species, giving the oak sprouts and seedlings a growth advantage (Little 1973, 1974). Even though some of the oak tops will be killed by the fire, vigorous sprouts often regain their preburn height in a single growing season.

Another difficulty in using prescribed fire is controlling fire intensity so that damage to the overstory is minimal. Damage to the overstory was considerable during the Road Run fire. If trees are to be removed soon after burning, fire-damaged trees can be salvaged. However, if overstory removal is delayed too long, severe decay can develop and more trees will die. For example, average scar length was 5.3 feet; for a 6-inch-diameter tree, mortality probability would be about 65 percent (Loomis 1973).

For success in regenerating oaks, Sander (1979) recommended that there should be at least 435 advance oak seedlings per acre that are 5 feet tall before overstory removal. The problem occurs in establishing and managing the oaks to grow to this threshold size. Acorns are subject to predation by insects, birds, and mammals—55 to 70 percent of mature acorns may be consumed. Oak seed crops are unpredictable and good seed crops may occur at 2- to 5-year intervals (Olson 1974), so it may take 15 to 25 years to build up an abundance of red oak advance reproduction during poor to fair seed years.

In stands with high density overstories and understories, light may be the limiting factor in the establishment and growth of oaks. Sander (1979) reported that 30 percent of full sunlight is needed to maximize photosynthesis in oak seedlings. In Missouri forests, this condition is achieved by maintaining 40 percent overstory stocking and eliminating understory vegetation (Sander 1979). Herbicides and/or fire has been suggested as a means of reducing understory competition. With herbicides, basal spraying achieves a semblance of selectivity; with fire, all stems—desirable or undesirable—are affected.

Table 5.—Advance reproduction 1.0 foot tall to 0.9 inch in d.b.h. on the unburned area before and 5 years later

Species	Time	Seedlings per acre	Sprouts per acre	Total	Stocking
		Number			*Percent*
		COMMERCIAL			
Hickory	Initial	0	1,429	1,429	14
	5 years	0	1,143	1,143	14
E. hophornbeam	Initial	1,143	0	1,143	57
	5 years	1,143	0	1,143	71
Red maple	Initial	571	143	714	57
	5 years	286	1,285	1,571	43
Red oak	Initial	143	0	143	14
	5 years	286	286	572	29
Chestnut oak	Initial	0	0	0	0
	5 years	286	0	286	29
Black locust	Initial	0	0	0	0
	5 years	0	286	286	0
Total	Initial	1,857	1,572	3,429	86
	5 years	2,001	3,000	5,001	86
		NONCOMMERCIAL			
Striped maple	Initial	3,286	714	4,000	86
	5 years	4,571	0	4,571	86
Dogwood	Initial	1,286	1,000	2,286	57
	5 years	5,571	1,286	6,857	86
Serviceberry	Initial	857	0	857	29
	5 years	143	857	1,000	29
Witch-hazel	Initial	429	0	429	29
	5 years	714	3,000	3,714	57
Total	Initial	5,858	1,714	7,572	100
	5 years	10,999	5,143	16,142	100

The data obtained on the Road Run fire indicate that the fire was poorly timed. Although there were a few stems of advanced oak reproduction on the area, they were too few on the area before burning to warrant burning. Perhaps a better procedure would have been to open up the overstory and reduce the understory in anticipation of a good seed crop. This would allow for oak establishment and growth. Where competition is a problem, burning can be used to control unwanted vegetation. Several light burns might be sufficient to allow the advanced oak reproduction to reach a height of 5 feet or more. When the oaks attain that height and are abundant and well distributed, the overstory should be removed. Sander (1979) indicated that this process may take 15 to 25 years.

Burning for silvicultural purposes in the central Appalachian hardwood forest is still unknown, so additional research will be needed to determine whether fire has a place in the management scheme. The high rainfall and relatively few "dry" days when fire can be used and the variation in sites and species composition present a challenge to using fire silviculturally in this region.

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A prescribed fire in a central Appalachian mixed hardwood stand caused considerable damage to the butt logs of many overstory trees. Although there were increases in the abundance and distribution of several species of hardwoods, advanced red and chestnut oaks were poorly distributed 5-years after burning. An abundance of striped maple and other shrubs in the understory poses a threat to the development of desirable tree species. More research is needed on timing of fire in relation to oak seed crops and on reducing competition before fire can be recommended as a regeneration tool in central Appalachian hardwood stands.

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Predicting Bunching Costs for the Radio Horse 9 Winch

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Abstract

Data from field studies and a prebunching cost simulator have been assembled and converted into a general equation that can be used to estimate the prebunching cost of the Radio Horse 9 winch. The methods can be used to estimate prebunching cost for bunching under the skyline corridor for swinging with cable systems, for bunching to skid trail edge to be picked up by a skidder or forwarder, or bunching to roadside for stand cleanings and firewood sales. Costs can be determined easily with a hand calculator. The equation can also be incorporated into larger stump-to-mill desktop and mainframe computer programs.

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Introduction

Because timber harvesting is shifting to young-growth stands, forest managers and loggers are faced with the challenge of matching logging equipment to stand conditions in order to maximize productivity and minimize costs. Harvests in young-stands entail moving large numbers of small logs; production rates are lower and logging costs higher. One method for increasing production is to prebunch logs (bunch prior to yarding, skidding, or forwarding) into decks with small relatively inexpensive winches thus allowing the more expensive swing, skidding, or forwarding machine to develop larger payloads. The expensive and time consuming task of prebunching logs is charged to the less expensive winch, whereas the high payload of the more expensive machine is efficiently used during swinging, skidding, or forwarding. Methods are presented for estimating the bunching costs of such a prebunching winch, the Radio Horse 9.[1]

Background

Prebunching has been applied widely to: helicopters (Dykstra and others 1978), cable systems (Kellogg 1976; Gonsior 1978, 1979; Mason 1979; Keller 1979; Zielinsky 1980), the helistat (Gibson and others 1982); and ground-based systems (Harou and others[2]). A simulation model called THIN (LeDoux and Butler 1981) has been developed to simulate prebunching operations. Sensitivity analysis and equipment configuration evaluations have been conducted (LeDoux and Butler 1982). Prebunching cost estimating methods have been developed and implemented for west coast logging conditions (LeDoux and Starnes 1986).

Recently, prebunching tests were conducted for the Radio Horse 9 winch on five southern New England sites (Harou and others 1985) (Table 1). The field studies quantified the variables that significantly affect the productivity and cost of the Radio Horse 9 winch. A general equation was developed for estimating the prebunching cost of the Radio Horse 9 winch using the data provided by Harou and others[2]; 1986 new equipment, labor, and fuel costs (Table 2); and the THIN (LeDoux and Butler 1981) prebunching simulation model.

[1]The use of trade, firm, or corporation names in this paper is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

[2]Harou, P. A.; Kling, B. W.; MacConnel, W.; Thompson, C.; Morin, D.; Zheng, C. Financial feasibility of the Radio Horse 9 winch. Cooperative Agreement 23–792. Final Report. Broomall, PA: 1985. U.S. Department of Agricultural, Forest Service, Northeastern Forest Experiment Station; 107 p.

Prebunching Cost Equation

Simulated, delay-free data points for prebunching cost were developed for the Radio Horse 9 winch under a wide range of diameter breast height (DBH), volume cut per acre (VOAC), and average slope yarding distance (SYD). The model stand contained 1,400 ft^3 per acre. The stand was thinned, using an arithmetic mean diameter of cut trees/arithmetic mean diameter of stand ratio (d/D ratio) of 1.0 to levels of 33 and 50 percent. The trees cut from each treatment were bucked into logs (LeDoux 1985) by d.b.h. and the pooled data points (Table 3) used to develop a general equation for prebunching cost by arithmetic mean DBH of cut trees, VOAC, and SYD:

$$\$/ft^3 = -0.12640 + 1.1965\,(1/DBH) + 0.00023\,(SYD) + 235.30853\,(1/(VOAC * DBH))$$

$$R^2 = 0.867$$

where:

DBH = Arithmetic mean tree diameter at breast height, in inches; variable limits = 4 to 12.

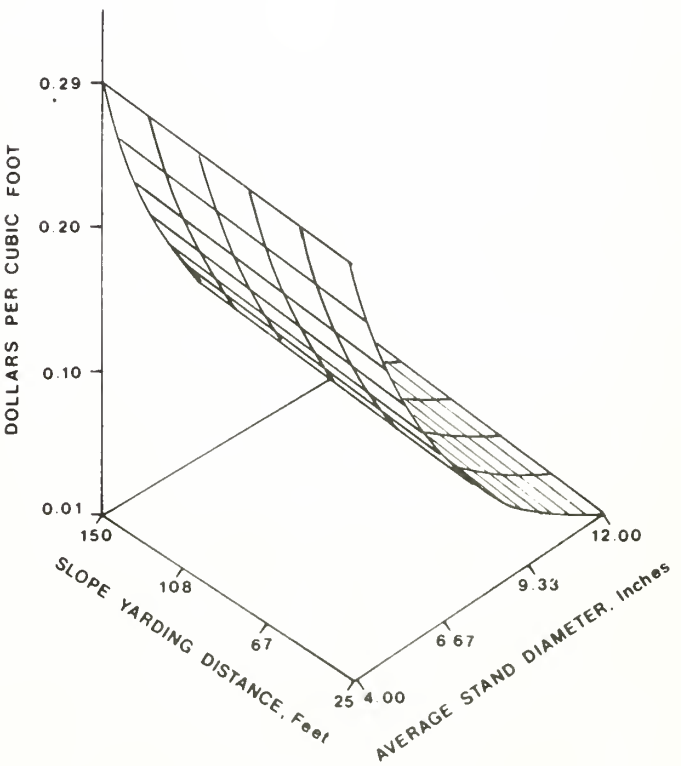

Figure 1.—Delay-free prebunching cost surface for the Radio Horse 9 winch, VOAC = 700 cubic feet.

Table 1.—Conditions for five field tests of bunching

Test and stand type	Average d.b.h.	Average stems removed	Average volume removed	Average side slope	Productivity	Cost per unit produced	Stand treatment
	Inches		*Cords/acre*	*Percent*	*Cords/hr*	*$/Cord*	
Test 1, White pine hardwood	9.5	132	11.2	0	1.9	12.17	Release cut to partially remove the overstory to enhance the growth of regeneration.
Test 2, Oak hardwood	7.5	176	11.0	47	1.9	12.78	Improvement cut bunched in a three-step process (included reyarding), downhill pull.
Test 3, Spruce pine plantation	7.8	162	4.7	22	0.4	60.58	Single tree selection thinning, brush made bunching across the hill difficult.
Test 4, Red maple swamp	8.1	247	11.0	0	2.0	11.06	Area wide thinning
Test 5, Hemlock hardwood	8.0	135	8.7	37	1.1	21.10	Improvement cut to make large hemlocks visible. Logs rolled downhill while being bunched.

Source: Harou, P. A.; Kling, B. W.; MacConnel, W.; Thompson, D.; Morin, D.; Zheng, C. Financial feasibility of the Radio Horse 9 winch. Cooperative Agreement 23-792. Final Report. Broomall, PA. U.S. Department of Agricultural, Forest Service, Northeastern Forest Experiment Station; 1985. 107 p.

Table 2.—Hourly bunching costs for the Radio Horse 9 winch[a]

Component	Cost
	Dollars/hr
Winch	12.55[b]
Chainsaw	2.65
Labor	*13.00[c]*
Total	28.20

[a]Includes all new equipment (1986 costs).
[b]Includes depreciation, insurance, interest, operating costs (fuel, oil, lubricants, maintenance, repair, and taxes) and rigging.
[c]One faller and a winch operator, rates obtained from cost guide for empirical appraisals, USDA Forest Service, Region 9, Amendment 112.

Table 3.—Log size parameters by d.b.h. for model stand

	Log size			
D.b.h.	Mean	Minimum	Maximum	Standard deviation
Inches	——————*Ft*^{3}——————			
3-4	1.75	0.24	4.36	0.89
5-6	4.62	1.36	10.40	2.04
7-8	7.71	1.60	15.35	3.21
9-10	11.65	2.20	28.27	5.22
11-12+	15.49	5.27	61.85	7.95

SYD = Average slope yarding distance, in feet; variable limits = 25 to 150.
VOAC = Average volume removed per acre, ft^3; variable limits = 462 to 700.

The equation is machine specific and the variable limits should be observed carefully. Figure 1 shows the delay-free prebunching cost surface for a volume removal of 700 cubic feet.

Delay-free costs must be adjusted to allow for nonproductive time. Delay percentage is the proportion of nonproductive time expressed as a percentage of total time. One minus the proportion of nonproductive time is the proportion of productive time. For example, if the delay is 10 percent, the proportion of nonproductive time is 0.1, and the proportion of productive time is 0.9. The delay-free cost is adjusted by dividing it by the proportion of productive time to get the cost with delay.

Prebunching Delays

Data for estimating delays are presented in Figures 2, 3, and 4. Generally, the Radio Horse 9 was productive (Fig. 2). Equipment, personnel, and hangup delays accounted for the bulk of the delay time. Closer inspection of the hangup delays (Fig. 3) reveals that most of the hangups were due to trees. Rocks, stumps, brush, and other logs made up the bulk of the hangup delays. Although the average slope yarding distance for the pooled data (all five sites) was 120.65 feet, most hangups occurred at a slope yarding distance of 75 feet (Fig. 4). The data from Figures 2 and 3 can be used to adjust the delay-free cost estimates. For example, a logger is estimating prebunching cost for a hardwood stand with an average arithmetic tree

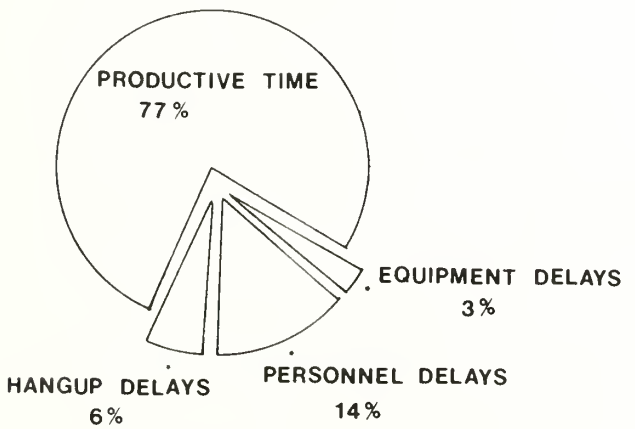

Figure 2.—Percentages of observed productive and delay time for the Radio Horse 9 winch.

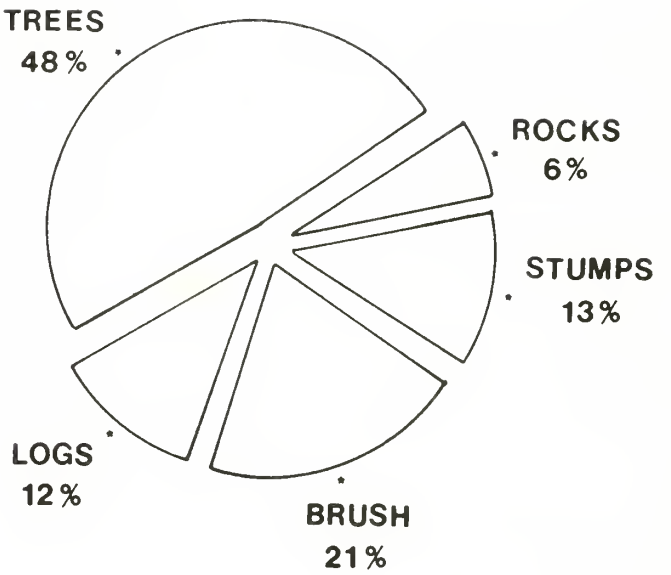

Figure 3.—Percentages of observed hangup delays for the Radio Horse 9 winch.

diameter at breast height of 8.0 inches, an average slope yarding distance of 100 feet, and an average volume removal of 700 ft^3. Delay-free bunching cost is:

= − 0.12640
+ 1.19650 (1/8.0)
+ 0.00023 (100)
+ 235.30853 (1/(700*8.0))
= 0.088

Adjusting delay-free cost with an average delay percentage of 0.23 (Fig. 2) = 0.088/(1-0.23) = 0.088/0.77 or \$0.114/ft^3. The delay percentages summarized in Figures 2, 3, and 4 are not exclusive, so users may wish to substitute their own delay percentage based on experience or observation.

Deck Spacing

The distance between prebunched decks significantly affects prebunching cost and productivity (LeDoux and Butler 1982). The farther apart the decks are constructed, the lower the productivity and the higher the prebunching costs. Constructing decks too close to each other could result in small decks and a substantial amount of time for moving and setting up the winch. An optimal deck spacing exists for each combination of stand operating conditions and winch configuration.

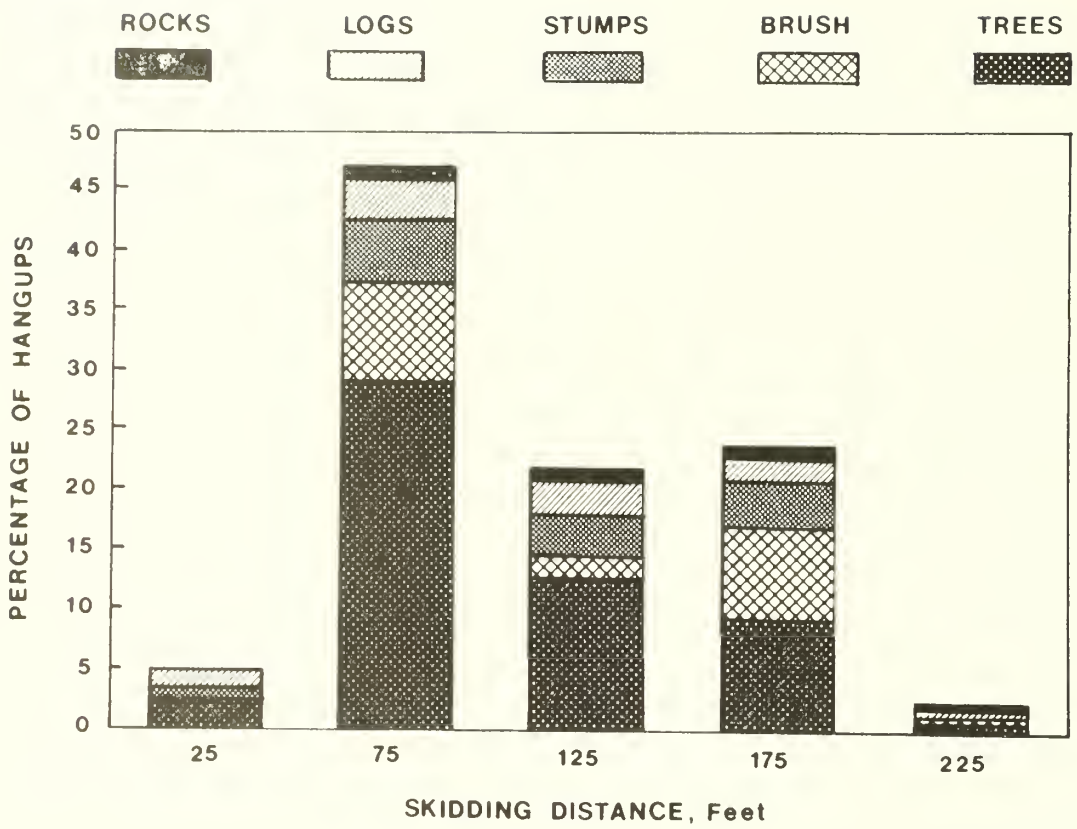

Figure 4.—Percentage of hangups by slope yarding distance for the Radio Horse 9 winch.

Accordingly, using the previously cited field data, stand conditions, and the THIN (LeDoux and Butler 1981) simulation model, we developed an optimal deck spacing for the Radio Horse 9 winch (Fig. 5). Results from the simulations suggest that deck spacings betwen 30 to 70 feet will result in maximum productivity and the minimum prebunching costs. Although the production rates and costs simulated for the extreme deck spacings may be optimistic, one would not normally expect to operate at the extremes.

Application of the Costing Methodology

To use the cost equation, the estimator will need to know (1) the arithmetic mean d.b.h. to be harvested; (2) the average volume cut per acre, in cubic feet; and (3) the average slope yarding distance. These items can be obtained from inventory data and cruise data, and the logging plan for the tract. The prebunching cost for a 10-acre tract is:

Delay-free cost (Dollars/ft^3)	*Average delay (Percent)*	*Cost with delay (Dollars)*
0.161	15	1,134

Cut trees are 6 inches d.b.h., the average volume cut per acre is 600 cubic feet, and the average slope distance is 100 feet.

Additional adjustments to these estimated costs may be necessary depending on their intended application. The estimated costs do not include an allowance for profit and risk, nor do they include recognition of the tax savings resulting from accelerated depreciation.

Consideration for Managers

The methods presented here provide a relatively complete packaging for estimating the cost for the Radio Horse 9 winch operating in most eastern hardwood stands. Estimates can be developed for prebunching under the skyline corridor for swinging with cable systems, for bunching to skid trail edge to be picked up by a skidder or forwarder, or bunching to roadside for stand cleanings and firewood sales.

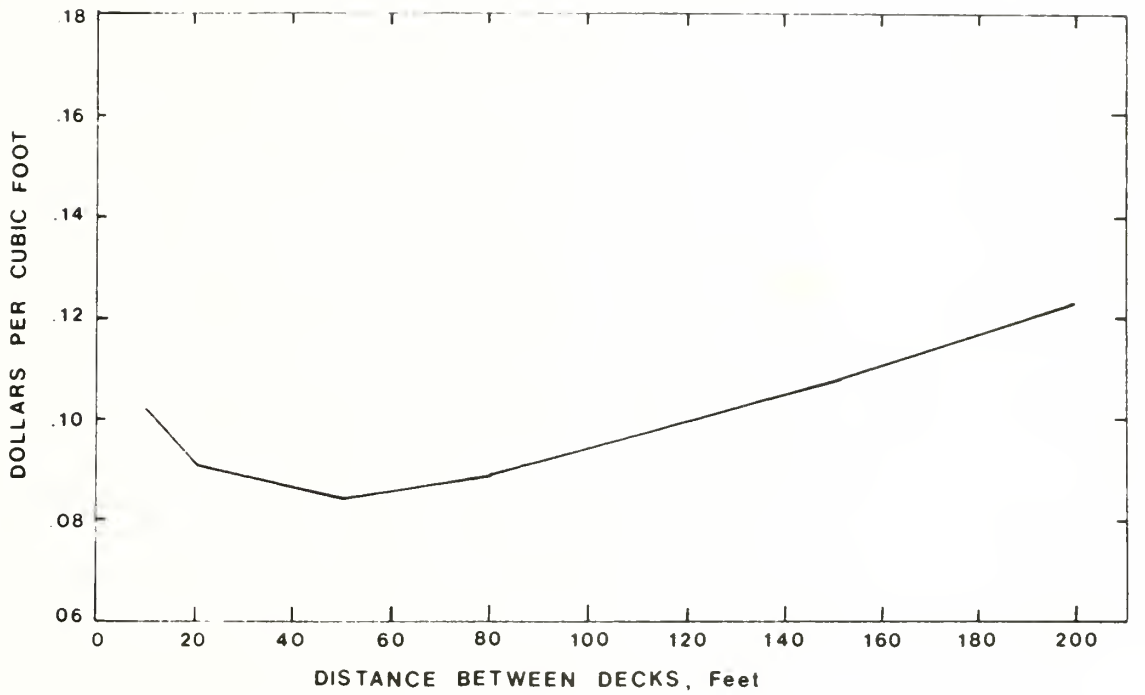

Figure 5.—Simulated total prebunching cost for various deck spacings for the Radio Horse 9 winch.

Production and related costs per unit produced will vary with stand and site conditions (Table 1). The methods presented here consider this variability in site and stand conditions. Although the methods likely will not produce bunching estimates that match actual outcomes exactly, reasonable estimates can be expected.

Prebunching winches have several advantages in that: (1) they are relatively inexpensive and labor requirements are minimal; (2) larger more expensive equipment is used most efficiently to swing, skid, or forward bunched decks to landings developing full payloads; (3) residual stand damage is kept to a minimum since the winches generally do not develop enough horsepower to "tear" things up; (4) soil compaction and understory vegetation disturbance is kept to a minimum because there is no equipment moving within the stand; (5) the small winches can be used in environmentally and esthetically sensitive areas eliminating in part the need for large noisy equipment; and the greatest advantage is that (6) prebunching improves the efficiency of the more expensive yarding, skidding, and forwarding equipment.

Prebunching should not be envisioned as the cure-all solution to harvesting in young stands. A considerable amount of planning and layout must be done to ensure an efficient prebunching operation. Deck locations must be identified and fallers instructed to gun trees toward the desired decking area to minimize hangups. Landing areas must be designed to handle the increased flow of logs during a swing, skidding, or forwarding operation. Hauling must be scheduled to avoid congested landings and to haul away the high volumes of prebunched logs arriving at the landing. Hooking and skidding crews must be instructed to load their respective systems close to capacity to ensure that any gains in prebunching are not offset by an improperly loaded system. Prebunching operations require as much planning as any other harvesting operation.

The blending of field test data, simulation methods, and nonlinear regression methods, such as those summarized here, will not provide all the answers a manager or logger needs on prebunching. Such methods, however, provide tools for estimating prebunching costs for managing young-growth hardwood stands.

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Data from field studies and a prebunching cost simulator have been assembled and converted into a general equation that can be used to estimate the prebunching cost of the Radio Horse 9 winch. The methods can be used to estimate prebunching cost for bunching under the skyline corridor for swinging with cable systems, for bunching to skid trail edge to be picked up by a skidder or forwarder, or bunching to roadside for stand cleanings and firewood sales. Costs can be determined easily with a hand calculator. The equation can also be incorporated into larger stump-to-mill desktop and mainframe computer programs.

Keywords: Prebunching; deck spacing.

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The Northern Hardwood Forest Ecosystem: Ten Years of Recovery from Clearcutting

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C. W. Martin
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Abstract

Two even-age management systems, progressive strip cutting and block clearcutting, have been studied since 1970 on small watersheds at the Hubbard Brook Experimental Forest, New Hampshire. In the strip cutting, all merchantable trees were harvested in a series of three strips over 4 years (1970–74). In the block clearcutting, all trees were harvested in a single operation in 1970. This paper contrasts progressive strip cutting and block clearcutting for the 10-year period after initiation of harvest in terms of hydrologic response, erosion losses, stream water ions, nutrient leaching, nutrient removals in harvested products, and natural regeneration of vegetation.

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COVER—**Harvested watersheds at the Hubbard Brook Experimental Forest in New Hampshire.**

Contents

The Study Area 2
Design and Methods 3
  Watershed Harvests 3
  Hydrology Studies 4
  Erosion Losses in Streamflow 5
    Weir Basin Data 5
    Turbidity Data 5
  Stream Water Ions and Nutrient Budgets 5
  Biomass and Nutrients in Harvested Products 6
  Regeneration 6
Results 6
  Hydrologic Response 6
    Strip Cutting 6
    Block Clearcutting 8
  Erosion Losses 8
  Stream Water Ions 9
    Calcium 9
    Potassium 9
    Magnesium 10
    Sodium 10
    Ammonium 10
    Hydrogen 10
    Nitrate 10
    Sulfate 11
    Chloride 11
    Cation-Anion Summary 12
  Nutrient Budgets 12
    Calcium 13
    Potassium 13
    Nitrate 13
    Sulfate 13
  Biomass and Nutrients Removed by Harvest 15
  Regeneration 15
Discussion 16
  Changes in Water Yield 16
  Erosion Losses in Streamflow 18
  Concentrations of Stream Water Ions 20
    Mechanisms Affecting Concentrations 20
    Sulfate 21
    Hydrogen 21
    Management Implications 22
  Evaluation of Nutrient Removals and Leaching Losses 22
    Calcium 24
    Potassium 24
    Magnesium 25
    Nitrogen 25
    Sulfur 25
    Phosphorus 25
Management Implications 25
  Regeneration 26
Conclusion 27
Acknowledgment 27
Literature Cited 28

Introduction

Northern hardwood forests in the Northeastern United States provide highly valued goods and services, including timber, recreation, esthetics, wildlife, and watershed protection. Because these products cannot always be obtained simultaneously, controversy sometimes arises over how best to use the resources of the northern hardwood forest.

The best known example is the conflict over the use of clearcutting for harvesting northern hardwoods (Horwitz 1974). Clearcutting is defined as the harvesting in one cut of all trees on an area for the purpose of creating a new, even-aged stand (USDA 1973). For forest managers, clearcutting is an attractive silvicultural method because it is economical and amenable to the increasing mechanization accompanying harvests, and it favors new stands with high proportions of commercially valuable species of *Betula* and *Acer*. On the other hand, since the late 1960's there has been an increased awareness of possible adverse effects of clearcutting on soil nutrients, water quality, wildlife, esthetics, and stand regeneration.

Some of the concerns about clearcutting have eased. Forest managers addressed the problem of esthetics by making clearcuts smaller, cleaning up debris to improve the appearance of the harvest site, and locating boundaries of cut areas to fit the landscape. But other concerns, such as those regarding soil nutrients, hydrology, and stand regeneration, could not be addressed adequately, and stimulated new research. This paper is an example, reporting research begun in 1970 at the height of the concerns over clearcutting. The study involves two types of clearcutting in northern hardwoods, block and progressive strip, and how each affects nutrient and hydrological cycling and stand regeneration. The results span 10 years, or from harvest well into the establishment of new stands.

Progressive strip cutting evolved from block clearcutting as an attempt to further favor regeneration of birches by more closely controlling variables such as distance to seed sources, light, moisture, and scarification of the seedbed. The method of strip cutting applied in our study is recommended by Marquis (1966) and Safford (1983) and entails cutting strips about 25 m wide oriented along the contour with 50–m–wide uncut strips between them. After a 2-year period for establishment of regeneration, a second series of 25–m strips are cut on the southernmost or westernmost side of the original cut. The remaining strips are then cut after a second establishment period of 2 years. As in block clearcutting, all merchantable stems are removed and scarification is encouraged during logging, with appropriate measures to avoid erosion (Marquis 1969; Filip 1969).

After the first strip is cut, it receives shade from the trees on its south or west border. This provides favorable conditions for germination and early survival. When the second strip is cut, it receives shade for initial establishment but also allows the first strip to receive direct sunight. Thus, both the first and second strips receive shade for seedling establishment, and then direct sunlight for best growth. During these harvests, seed sources are close by in the uncut strips. When the third strip is cut, it receives only minimal shade, and seed sources are more distant. However, *Betula* and *Acer* seedlings that survive the first year or two of direct sunlight then have optimal growing conditions in terms of light and moisture.

By stretching over 4 years, strip cutting would seem to lessen some of the environmental concerns surrounding block clearcutting. The strips of varying ages of living vegetation minimize erosion and leaching of nutrients to streamflow. However, testing is needed to determine if advantages of strip cutting in terms of stand regeneration and protection of site and stream water outweigh the convenience and economics of block clearcutting. Our study addresses some of these questions.

The Study Area

Our study was conducted on the 3,000-ha Hubbard Brook Experimental Forest in West Thornton, New Hampshire. Hubbard Brook is operated by the USDA Forest Service's Northeastern Forest Experiment Station. Four small watersheds were used: watershed 6, an untreated control for the nutrient cycling studies, is 13 ha; watershed 3, an untreated control for the hydrologic studies, is 42 ha; watershed 4, which was strip cut, is 36 ha; and watershed 101, which was clearcut as a block, is 12 ha (Fig. 1). The watersheds extend from 450 to 800 m above sea level and have southerly aspects and average slopes of 20 to 30 percent.

Descriptions of the study sites have been given in previous publications of the Hubbard Brook Ecosystem Studies. Vegetation has been described by Bormann et al. (1970) and Siccama et al. (1970). The biogeochemistry is described in Likens et al. (1977), and the hydrology and climate in Hornbeck et al. (1970). Soils on the study watersheds are derived from coarse-textured, glacial till material that has been subjected to frost action, erosion, and deposition since glacial retreat about 14,000 years ago. Till depths range from 0 to 5 m. The surficial layers have weathered to form fine sandy loams classed as Lithic and Typic Haplorthods. Soil profiles often are mixed due to treethrow, but usual development includes O, E, Bhs, Bs, and C horizons that differ markedly in physical and chemical properties. Soil depths average 0.5 m on top of a dense basal till nearly impermeable to roots and water. The more common soil series include Marlow, Lyman, Peru, Hermon, and Monadnock.

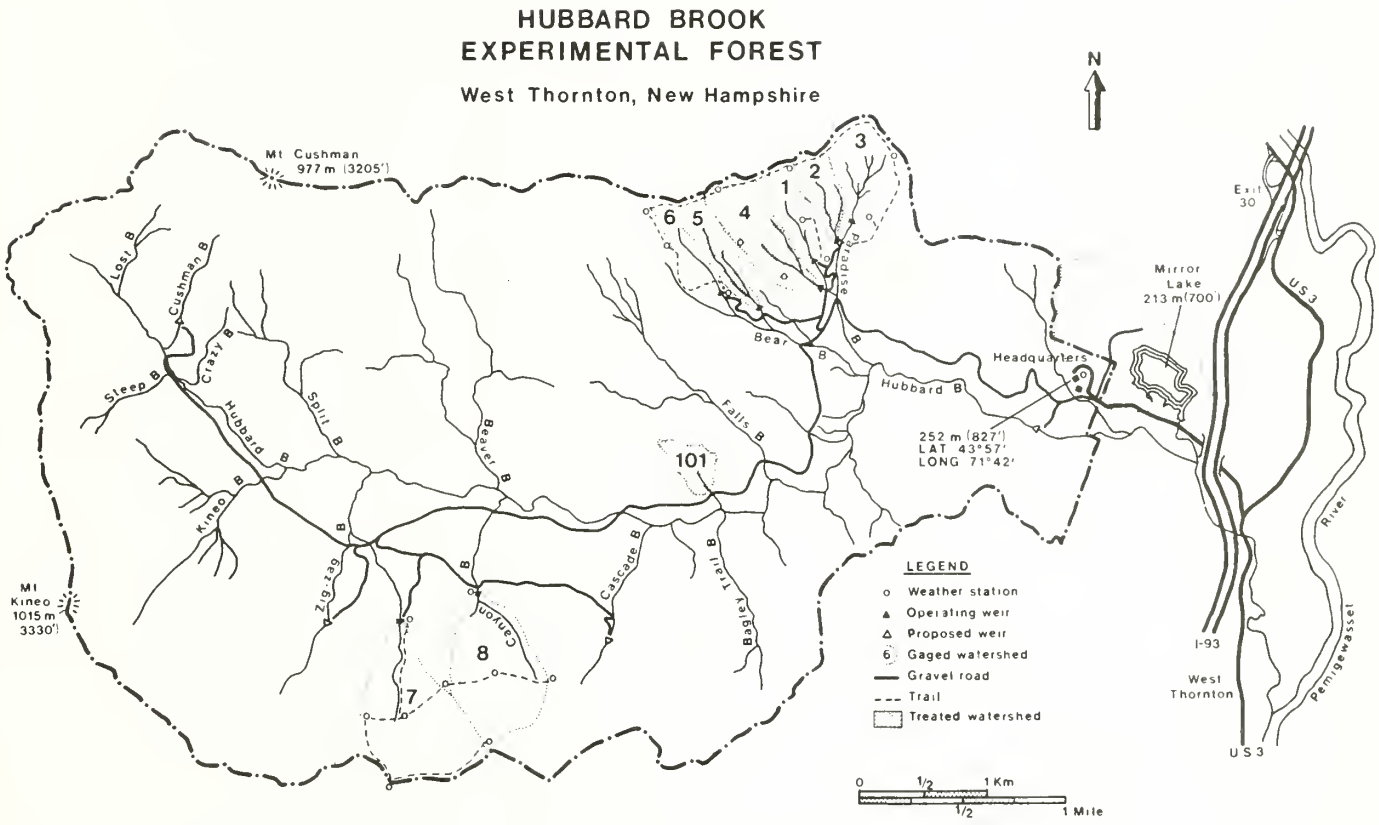

Figure 1.—The Hubbard Brook Experimental Forest and location of study watersheds 3, 4, 6, and 101.

Design and Methods

Watershed Harvests

In preparation for harvest, watershed 4 was surveyed into 49 strips, each 25 m wide. The strips were oriented from east to west roughly parallel to watershed contours. Harvests were done in the autumn months, generally a favorable time for minimizing logging disturbance. The first series of strips was harvested from September 28 to October 29, 1970, the second series from September 7 to October 1, 1972, and the third series from October 1 to November 1, 1974 (Fig. 2). A variable-width buffer strip of uncut trees, from 15 to 25 m wide, was left on both sides of the major stream channel to minimize solar heating and sedimentation of streams.

The block clearcut on Watershed 101 (Fig. 3) was carried out from October 30 to November 28, 1970, or immediately after harvest of the first series of strips. No streamside buffer strip was left during the block clearcutting.

On both the strip cut and block clearcut, all trees and snags more than 2.5 cm in d.b.h. were felled. Merchantable tree boles as determined by the operator were transported by rubber-tired skidders to landing areas adjacent to the base of the harvested watersheds. Tops and branches were left on site, but were moved if they fell in stream channels. Main skidder trails were laid out generally along ridges, well away from streams in accordance with USDA Forest Service specifications. Culverts were used at stream crossings and water bars were placed on skid trails immediately after completion of logging. Skidder operators were encouraged to vary their routes to provide scarified conditions necessary for successful germination and growth of birch seed. In general, every effort was made to perform an ecologically sound logging operation that would encourage regeneration yet minimize damage to forest soils and streams.

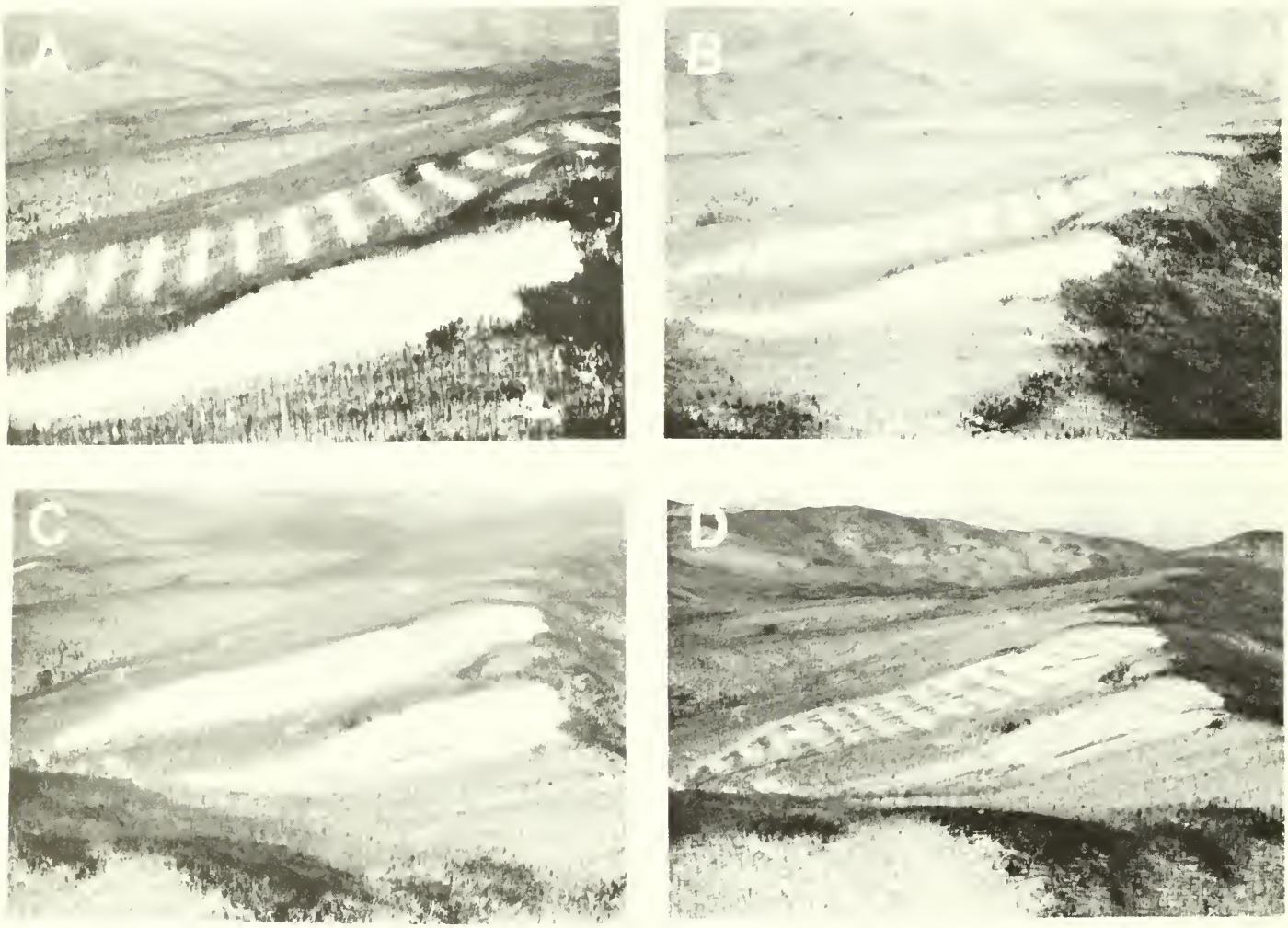

Figure 2.—East to west views across strip-cut watershed showing: (A) first strip cut; (B) first and second strips cut; (C) all strips cut; (D) regeneration at 10 years after initial harvest. Cleared area in foreground is an earlier deforestation experiment on Hubbard Brook watershed 2 (see Pierce et al. 1970).

Hydrology Studies

Volume of precipitation is sampled by a network of standard and recording gages that have a density of one gage per 15 ha of watershed area. Streamflow from watershed 3, the control for the hydrology studies, and from watershed 4, the strip-cut watershed, is measured continuously with 120° V-notch weirs (Reinhart and Pierce 1964). Streamflow from watershed 6, the control for the nutrient cycling studies, is measured with a tandem 60-cm-wide flume and a 90° V-notch weir. A water year of June 1 through May 31 is used for summarizing and analyzing hydrologic data at Hubbard Brook (Likens et al. 1977).

Effects of the strip cutting on water yield have been determined using the control watershed concept. For 9 years before treatment, streamflow values from watershed 4 and control watershed 3 were used to develop linear regression equations between the two watersheds. Separate regressions were prepared for various streamflow values, including monthly, seasonal, and annual totals. After strip cutting, streamflow values from watershed 3 (the control) were used in the equations to determine what the streamflow values would have been for watershed 4 had it not been strip cut. As an example, the water year equation is:

Estimated flow
from watershed 4 = 1.54 + 1.03 (flow from control)

A difference in streamflow between the actual watershed 4 measurement and the estimated flow for the same watershed was considered statistically significant and was attributed to strip cutting if the deviation exceeded the 95 percent confidence interval about the regression line.

Watershed 101, the site of the block clearcutting, does not have a stream gage. Instead, daily streamflow was simulated using BROOK, a hydrologic model developed and tested on forested watersheds at Hubbard Brook and also tested at other locations (Federer and Lash 1978a,b). The decision to use simulation rather than a gaged watershed was based on three factors: (1) remaining gaged watersheds at Hubbard Brook were needed for future studies, (2) earlier studies have successfully demonstrated the use of hydrologic simulation (Sollins et al. 1980; Leaf and Alexander 1975), and (3) hydrologic models have become sophisticated and tests show that they are capable of highly accurate estimates of measured streamflow (Singh 1982). Regarding the last point, we tested BROOK by simulating several years of pre- and post-harvest streamflow from the strip-cut watershed. Monthly sums of simulated daily flows were within ± 3 percent of measured flow except for a few summer months which had total flows of less than 0.5 cm. Thus the capability of the BROOK model to simulate streamflow usually is within the 3- to 5-percent error range associated with stream gaging (Hornbeck 1965).

Inputs required to run BROOK, including daily air temperature and precipitation, were collected at watershed 6 about 1.5 km to the east. Various parameters used in the model, such as leaf area index, stem area index, and depth of the rooting zone, were adjusted to simulate flow during the postharvest period. Streamflow was simulated for the same period using parameters for an undisturbed forest. Differences in streamflow for the two simulations were attributed to harvest.

Erosion Losses in Streamflow

Erosion and resulting losses of organic and inorganic particulate matter in streamflow are extremely difficult to quantify for forests. Fortunately, erosion usually is not serious in undisturbed northern hardwood forests; with proper precautions, it can be controlled during and after harvests (Patric 1976; Patric et al. 1984). In our study, care was taken to minimize erosion. However, to ensure that a large increase of eroded material and associated nutrients did not go undetected, we periodically measured material trapped in the weir basins, and also sampled stream turbidity, a commonly used index of suspended material.

Weir basin data. Eroded material can leave the watershed in particulate form, either as suspended load transported by turbulent water or as bedload moving along the bottom of the stream channel. As streams leave the watershed, velocity is slowed by the weir basins, and heavier particulate matter settles out. The weir basins for the control and strip-cut watersheds have been cleaned, and oven-dry weights of the material removed have been obtained on an annual basis since 1965.

Turbidity data. Suspended particulate matter that normally would not settle in the weir basin was sampled by turbidity measurements. Grab samples were obtained periodically during nonstorm periods and during most storm events. Sampling was continued for 6 years after initiation of the strip cutting and for 3 years after block clearcutting. The longer interval for the strip cutting was needed to span the three separate harvests.

Samples were analyzed with an electronic turbidimeter and results expressed as Jackson Turbidimeter Units (JTU). A value of less than 1 JTU represents clear water while a value of several hundred JTU represents a large amount of suspended material. Turbidity cannot be used to quantitatively express erosion losses, but turbidity values do indicate whether sizeable amounts of eroded materials are reaching the stream channel and leaving the watershed.

Stream Water Ions and Nutrient Budgets

Details of methods used in collecting and analyzing stream samples are given in Likens et al. (1977). Briefly, weekly grab samples were collected just above the weirs on watersheds 4 and 6 since 1963, and at the lower boundary of

Figure 3.—Block clearcut is in foreground. Strip cut and an earlier deforestation experiment are at upper right.

watershed 101 since 1969. The samples were returned to the laboratory and analyzed for pH, specific conductance, and chemical ions, including Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, NH_4^{+}, SO_4^{2-}, NO_3^{-}, and Cl^{-}. THe pH was determined potentiometrically, the anions and NH_4^{+} by automated colorimetric analysis, and the cations by atomic absorption; PO_4^{3-} was measured during part of the study, but usually was below the detection level of 0.003 mg L^{-1}. Effects of harvest on stream water ions usually were obvious, and were easily demonstrated with graphs. We plotted mean monthly concentrations obtained by weighting individual weekly values for volume of streamflow, and then averaging over the month.

Nutrient budgets were determined by converting the ionic concentrations of precipitation and streamflow to inputs and outputs as mass per unit area. Daily inputs and outputs are calculated as the product of the ionic concentration (mg L^{-1}) in the weekly sample times volume (L) of water for each day represented by the sample. The same regression technique described for water yield studies was used to determine effects of harvest on nutrient outputs.

Biomass and Nutrients in Harvested Products

During harvest, pulpwood and sawlogs were scaled at landings located at the base of the strip-cut and block-clearcut watersheds. The scale data were converted to solid cubic volume by a formula for truncated cones. Constants developed at Hubbard Brook by Whittaker et al. (1974) were applied to convert the volumes to oven-dry weight of biomass in bark, heartwood, and sapwood. Nutrient contents of these three components are available from chemical analyses of plant tissues made at Hubbard Brook (Likens and Bormann 1970). The estimate of nutrient removal in kg ha^{-1} was obtained by multiplying biomass by percent nutrient content for elements of interest.

Regeneration

Regeneration on the block-clearcut and strip-cut watersheds has been surveyed on permanent plots at intervals of 1 to 3 years since harvest. Detailed results will be reported in a separate paper, but a summary of regeneration at years 2 and 10 after harvest is included in this paper. The summary is based on surveys of fifty-seven 25 by 25-m plots on the strip cut, and forty-eight 25 by 25-m plots on the block clearcut. Plots on the strip cut were chosen randomly after stratification by elevation and year cut. Plots on the block clearcut were chosen at random with no stratification since the harvest was completed in a single operation and the elevation range of the entire harvest area was about the same as for the mid-elevation plots on the strip cut.

A nested design was used for sampling each plot. The entire 25 by 25-m plot was used to sample trees more than 10 cm in d.b.h. Trees between 2 and 10 cm d.b.h. were tallied on a 1 by 25-m strip running the length of either the east or west side (decision by coin toss) of each plot. Lesser vegetation was surveyed on four 1-m^2 subplots spaced evenly along the 1 by 25-m strip plot. Within each of these subplots, stem counts were made by species for trees, shrubs, and herbs less than 0.5 m tall and for those more than 0.5 m tall. Visual estimates of percent of plot covered were used in place of stem counts for grasses, sedges, rushes, and mosses. Data from the subplots were averaged to give stems per m^2 for each 1 by 25-m strip.

Estimates of aboveground biomass of regeneration were obtained by establishing 46 additional plots on the strip-cut watershed, stratified by elevation and year cut. On these plots, individual species were clipped, grouped according to height or d.b.h. class, and oven dried at 105°C. Stem counts for individual species from the regeneration survey were multiplied by corresponding oven-dry weights to obtain biomass estimates on a kg ha^{-1} basis.

Results

Hydrologic Response

Strip cutting. Removal of the forest by strip cutting caused streamflow to increase in the 4 water years spanning harvest and for 3 additional years (Table 1). The annual increases ranged from 22 to 114 mm. The minimum value occurred the first year after the first set of strips was harvested, and coincided with below-average precipitation (Table 1). The maximum value occurred with two-thirds of the watershed harvested and coincided with an annual precipitation that exceeded the long-term average by 40 percent. Above-average precipitation is recognized as necessary for optimum increases in streamflow from deforested areas (Douglass and Swank 1972). Increases or decreases in water yield were statistically significant in 9 of the 10 years after harvest, and totaled 397 mm or 4 percent more than would have occurred if the watershed had not been harvested. Over three-fourths of this increase occurred in the first 5 years, or while the watershed was in the process of being harvested.

Most of the annual increase occurred during the growing season (Table 1). Thus, streamflow increases resulted primarily from a reduction in transpiration and canopy interception rather than from increased snow accumulation within the strips. As further evidence, changes in streamflow for the dormant season (October through May) and the period of major snowmelt runoff (March 1 through May 15) usually were small and not statistically significant (Table 1).

Table 1.—Streamflow and precipitation for strip-cut and block-clearcut watersheds, in millimeters (cutting on both watersheds began in 1970)

Year after cutting	Streamflow, strip-cut watershed			Streamflow, block-clearcut watershed			Precipitation	
	Estimate if uncut	Actual	Change due to cutting	Simulated for uncut	Simulated for cut	Change due to cutting	Actual	Departure from 23-year mean
				WATER YEAR (JUNE-MAY)				
1[a]	776	798	+22*	769	1046	+278	1222	−84
2[a]	1032	1078	+46*	1007	1163	+155	1505	+199
3[b]	1417	1531	+114*	1363	1455	+92	1833	+527
4[b]	819	886	+67*	777	816	+39	1239	−67
5[c]	1263	1318	+55*	1221	1260	+41	1659	+353
6[c]	868	949	+81*	876	896	+20	1323	+17
7[c]	973	1042	+69*	1031	1046	+15	1431	+125
8[c]	884	870	−14	888	893	+8	1286	−20
9[c]	755	725	−30*	743	744	+1	1138	−168
10[c]	796	769	−27*	844	840	+4	1261	−45
Total	9583		411	9519		653		
				GROWING SEASON (JUNE-SEPT)				
1[a]	52	80	+28*	46	208	+237	402	−44
2[a]	156	192	+36*	114	254	+140	487	+44
3[b]	368	459	+91*	324	409	+85	703	+257
4[b]	139	177	+38*	98	143	+45	519	+73
5[c]	217	298	+81*	196	232	+36	611	+165
6[c]	100	138	+38*	77	99	+22	489	+43
7[c]	80	107	+27*	108	118	+10	489	+43
8[c]	91	93	+2	84	90	+6	316	−130
9[c]	57	63	+6	58	63	+5	379	−67
10[c]	31	31	−0	30	35	+5	382	−64
Total			347			592		
				DORMANT SEASON (OCT-MAY)				
1[a]	759	755	−4	748	756	+8	773	−87
2[a]	724	719	−5	725	766	+41	820	−40
3[b]	873	887	+14	894	909	+15	1018	+158
4[b]	1038	1071	+33	1039	1046	+7	1130	+270
5[c]	676	709	+33	680	674	−6	720	−140
6[c]	1041	1019	−22	1024	1029	+5	1048	+188
7[c]	766	800	+34	876	896	+20	834	−26
8[c]	893	935	+42*	1031	1046	+15	942	+82
9[c]	792	777	−15	888	893	+5	970	+110
10[c]	697	662	−35	743	744	+1	759	−101
Total			77			110		

Continued

Table 1.—Continued

Year after cutting	Streamflow, strip-cut watershed			Streamflow, block-clearcut watershed			Precipitation	
	Estimate if uncut	Actual	Change due to cutting	Simulated for uncut	Simulated for cut	Change due to cutting	Actual	Departure from 23-year mean
				SNOWMELT (MARCH 1-MAY 15)				
1[a]	472	473	+1	503	502	−1	[d]	
2[a]	515	510	−5	478	470	−8	[d]	
3[b]	461	489	+28	471	450	−21	[d]	
4[b]	454	459	+5	594	576	−18	[d]	
5[c]	402	421	+19	318	312	−6	[d]	
6[c]	496	491	−5	521	496	−25	[d]	
7[c]	463	485	+22	473	476	+3	[d]	
8[c]	336	347	+11	470	469	−1	[d]	
9[c]	595	572	−23	571	554	−17	[d]	
10[c]	340	325	−15	301	296	−4	[d]	

* Significant at 0.05 level of probability.
[a] One-third of strip-cut watershed harvested.
[b] Two-thirds of strip-cut watershed harvested.
[c] Entire strip-cut watershed harvested.
[d] Precipitation for this period not related to streamflow.

Although strip cutting did not change the volume of snowmelt runoff, it did affect timing. With reduced shade after harvest, snow melted more quickly and snowmelt runoff was advanced. In monthly analyses (Fig. 4), this effect shows as an increase in streamflow for March or April, the first month of major snowmelt. Decreases in streamflow then occur in 1 or 2 following months, while in undisturbed watersheds, snowmelt progresses at the usual speed. The increases and decreases during snowmelt months balance closely.

Block clearcutting. On the basis of streamflow simulation, block clearcutting caused streamflow to increase by 278 mm, or 36 percent in the first year after harvest (Table 1). The increases tapered off rapidly with revegetation, and annual streamflow was nearly like the control watershed by the sixth year of regrowth. Total increase in streamflow for the 10-year period of study was 653 mm, or 7 percent more than if the watershed had not been harvested. As with the strip cutting, most of the annual increase occurred in the growing season (Table 1). Snowmelt runoff was advanced slightly more than on the strip cut due to the absence of uncut strips.

Erosion Losses

For the 6 years before harvest, erosion losses measured as material trapped in the weir basins averaged 33.6 ± 17.2 kg ha^{-1} for the control watershed and 40.4 ± 25.1 kg ha^{-1} for the strip cutting. Averages for the 10-year postharvest period were 37.7 ± 10.8 kg ha^{-1} for the control watershed and 36.7 ± 28.7 kg ha^{-1} for the strip cutting. Thus, strip cutting did not result in any important changes in amounts of material leaving the watershed as bedload or heavy particulate matter.

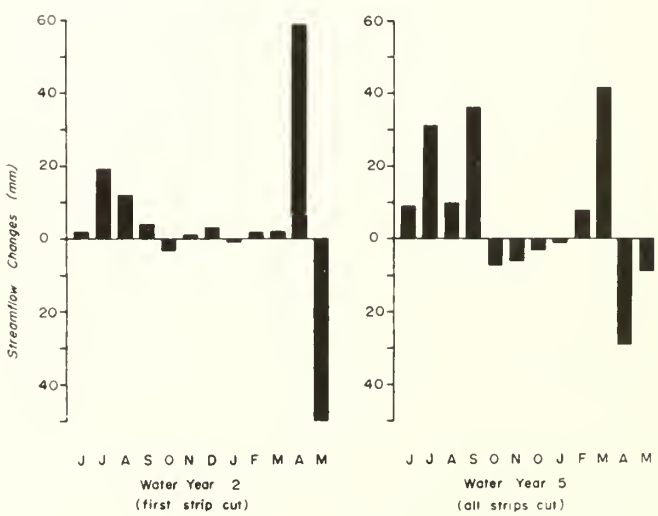

Figure 4.—Change in streamflow, by month, for 2 selected years after strip cutting.

The conclusion is the same for suspended materials as determined by turbidity measurements. During and after harvest, 325 samples were collected for turbidity analysis from both the control and strip cut, and 160 samples were collected from the block clearcut. A summary of these samples by turbidity class is shown in Table 2. About one-half of the samples were collected during storm events and should represent maximum effects of harvest.

The 11 samples falling in the 11–40 JTU class probably are the result of logging disturbances, especially since no corresponding values occurred for the control watershed. A more important point is that turbidity values remained quite low and exceeded 1 JTU on few occasions.

Stream Water Ions

Calcium. Before harvest, concentrations of Ca^{2+} averaged about 2 mg L^{-1} on the strip-cut watershed and just over 1 mg L^{-1} on the control and block-cut watersheds (Fig. 5). The concentrations were fairly stable throughout the year, and there were no obvious seasonal patterns.

Strip cutting caused Ca^{2+} to increase slightly, mostly during the dormant seasons (Fig. 5). The best example was in the dormant season 1 year after harvest of the first strip when Ca^{2+} was increased by an average of 0.8 mg L^{-1}. The increases were smaller in subsequent dormant seasons, even with cutting of the second and third sets of strips.

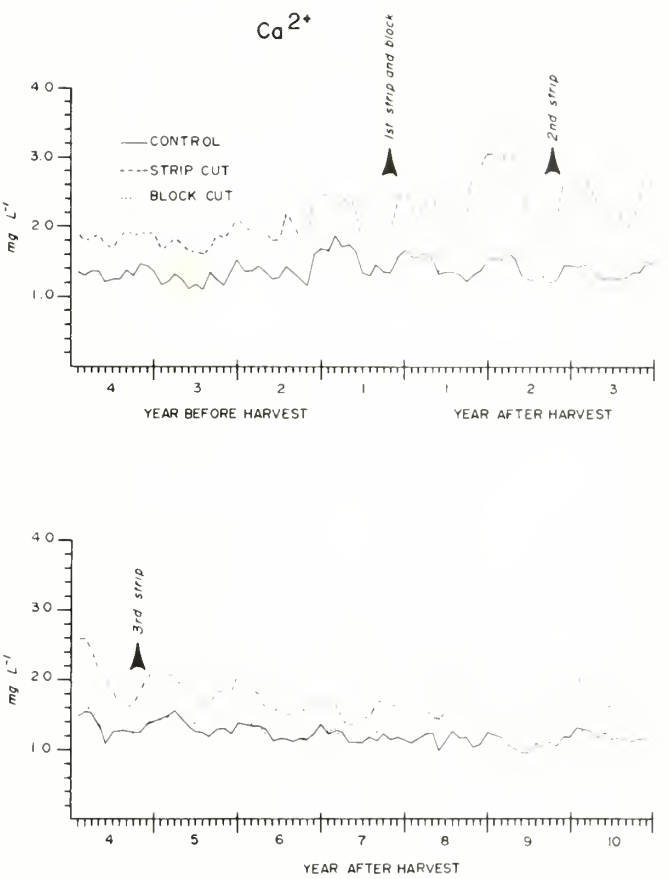

Figure 5.—Weighted, mean monthly Ca^{2+} in stream water, by calendar year.

Table 2.—Number of samples collected for post-harvest turbidity analysis

Item	Jackson Turbidimeter Units			
	<1	1–5	6–10	11–40
Control				
Nonstorm periods	175	3	0	0
Storm events	143	4	0	0
Total	318	7	0	0
Strip cut				
Nonstorm periods	171	2	2	3
Storm events	130	9	2	6
Total	301	11	4	9
Block clearcut				
Nonstorm periods	52	5	1	1
Storm events	88	10	2	1
Total	140	15	3	2

The block cut caused a similar pattern. Effects were greatest in the dormant season 1 year after harvest; Ca^{2+} concentrations from the block cut exceeded values for the control watershed by about 3 mg L^{-1} (Fig. 5). The effects of block cutting then declined gradually and were minimal by the end of the third year after harvest.

Potassium. Preharvest levels of K^{+} averaged 0.2 mg L^{-1} for the study watersheds (Fig. 6). A seasonal pattern of low values in summer and a rise to higher concentrations in winter is correlated with vegetation activity (Johnson et al. 1969). Potassium concentrations for the strip-cut watershed increased immediately after cutting and on average were about 0.1 mg L^{-1} higher than on the control during the 2 years after the first strip cut; 0.2 to 0.3 mg L^{-1} higher after the second sets of strips was cut; and 0.3 to 0.6 mg L^{-1} higher after the third set was cut. As with Ca^{2+}, the treatment effect was greatest in the dormant season. Unlike Ca^{2+}, the increases have persisted and the maximum

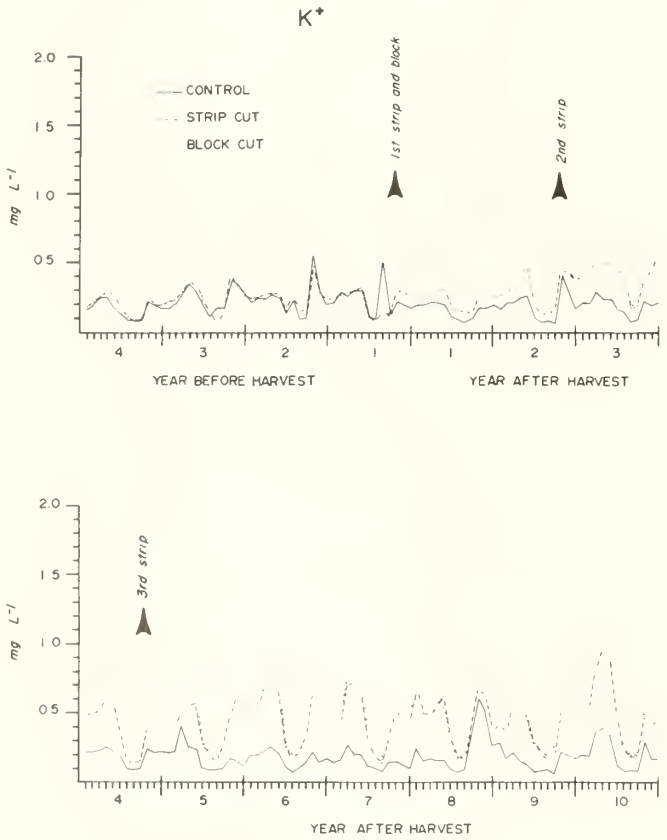

Figure 6.—Weighted, mean monthly K^+ in stream water, by calendar year.

increase of 0.6 mg L^{-1} occurred in April of the 10th year after harvest.

Potassium concentrations also responded immediately to block clearcutting. By the end of the second dormant season they were 5 times higher from the block clearcutting than from the control watershed (Fig. 6). Concentrations have declined since then, but the effects of cutting remain evident through the 10th year of regrowth.

Magnesium. Magnesium in stream water averaged about 0.4 mg L^{-1} before harvest and did not fluctuate with season or discharge. Effects of harvest occurred at the end of the first summer after cutting; there was an increase of 0.2 mg L^{-1} on the strip cut and 0.5 mg L^{-1} on the block cut. The increases persisted at declining levels for 1 1/2 years on the block cut. There were increases of less than 0.1 mg L^{-1} on the strip cut until 1 year after the final set of strips was harvested.

Sodium. Before harvest, Na^+ concentrations were fairly stable at about 1 mg L^{-1}, though peaks of up to 2 mg L^{-1} sometimes appeared in late summer. In the first 5 years after the start of strip cutting, many of the monthly values showed statistically significant increases, but the average increase for the period was less than 0.2 mg L^{-1}. Block cutting caused Na^+ concentrations to increase by a maximum of 0.2 to 0.3 mg L^{-1}, but the increases did not last beyond the second year after harvest.

Ammonium. Ammonium in streams from an undisturbed forest seldom exceeds 0.1 mg L^{-1} and usually is less than 0.02 mg L^{-1}. Strip cutting and block clearcutting had no detectable effect on NH_4^+ in stream water.

Hydrogen. Results are illustrated by a plot of weighted, monthly means of H^+ expressed as both mg L^{-1} and pH (Fig. 7). Streams from the three study watersheds had small but consistent differences in H^+ during the preharvest period. These differences of 0.002 to 0.020 mg L^{-1}, spanning a pH of 4.7 to 5.7, are typical of natural variation between watersheds at Hubbard Brook (Johnson 1979).

Strip cutting caused H^+ in streamflow to be more variable and slightly elevated in the second and third years of harvest (Fig. 7). During these 2 years, H^+ averaged 0.005 ± 0.003 mg L^{-1}, representing an average increase in H^+ of 0.002 to 0.003 mg L^{-1}, or a decrease in pH from 5.7 to 5.3.

For the block clearcutting, increases in H^+ appeared in the first spring after harvest, and elevated levels of 0.010 to 0.025 mg L^{-1} occurred through the second summer after harvest (Fig. 7). On the basis of the pretreatment relationship with the control watershed, these values represent an average increase of about 0.004 mg L^{-1}, or a decline in pH from 5.0 before harvest to 4.8 for the first 2 years after harvest. After the second summer, H^+ in stream water declined gradually to 0.002 to 0.004 mg L^{-1} (pH 5.4 to 5.7), or below the average of 0.010 mg L^{-1} (pH 5.0) that occurred for the watershed during preharvest.

Nitrate. During the calibration period, streams from the study watersheds showed cyclic NO_3^- concentrations related to seasonal growth patterns of vegetation. Minimum concentrations of 0.05 mg L^{-1} occurred in summer and autumn. The concentration rose in late autumn as vegetation became dormant, reaching maxima of up to 5 mg L^{-1} in March or April, then decreasing to low levels in May and June (Fig. 8).

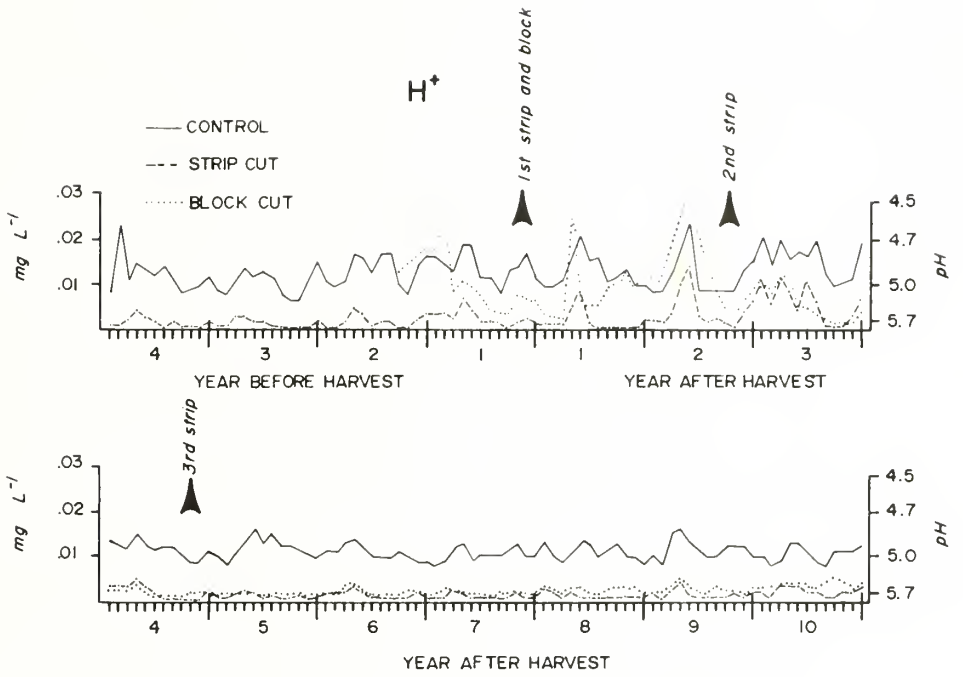

Figure 7.—Weighted, mean monthly H^+ and pH in stream water, by calendar year.

Nitrate increased immediately after strip cutting and remained higher than on the control watershed for 4 years. Average mean monthly concentrations were 2 mg L^{-1} higher than on the control for the first year after cutting, and 4 mg L^{-1} higher for the second year. After the second set of strips was cut, NO_3^- remained higher, but differences between watersheds were smaller. In year 6, NO_3^- for the strip cut dropped below the control and remained there through the 10th year (Fig. 8).

Nitrate did not respond to block cutting for 7 months, then rose over the next 11 months to a maximum of 26 mg L^{-1} (Fig. 8). This is an estimated increase of 23 mg L^{-1} compared with the control watershed. The NO_3^- concentrations then fell off rapidly and have been less than those on the control watershed since the middle of the third year after harvest.

Sulfate. Sulfate is the dominant anion in streams from the study watersheds. Seasonal patterns of SO_4 in streams from undisturbed forests usually show a gradual rise through the growing season to peaks of around 7 mg L^{-1} in late autumn and early winter, then a decline through the winter, reaching minimum concentrations of about 5.5 mg L^{-1} in late spring (Fig. 9).

Sulfate decreased after strip cutting. The decrease was most pronounced during late autumn and early winter of the first year after the first set of strips was cut. During this period, concentrations from the strip-cut watershed were about 1.5 mg L^{-1} below control watershed values (Fig. 9). Cutting the second and third sets of strips had less impact on SO_4^{2-}, and the control and strip-cut watersheds seldom differed by more than 0.5 mg L^{-1}.

The impact of block cutting on SO_4^{2-} is more difficult to discern. During the short time when determinations were made before cutting, SO_4^{2-} from the watershed to be block cut was below SO_4^{2-} from the forested control (Fig. 9). This difference continued after cutting, with maximum differences of more than 2 mg L^{-1} in the last half of the first and most of the second year after harvest. During the third and fourth years, SO_4^{2-} from the block cut began to approach values for the control, indicating that the differences in the 2 previous years were due to cutting.

Chloride. Chloride concentrations during preharvest averaged 0.5 mg L^{-1} for all study watersheds, and there were no seasonal patterns. In the summer after cutting of the first set of strips there was a mean increase of about 0.1 mg L^{-1}. The increase disappeared by winter and there

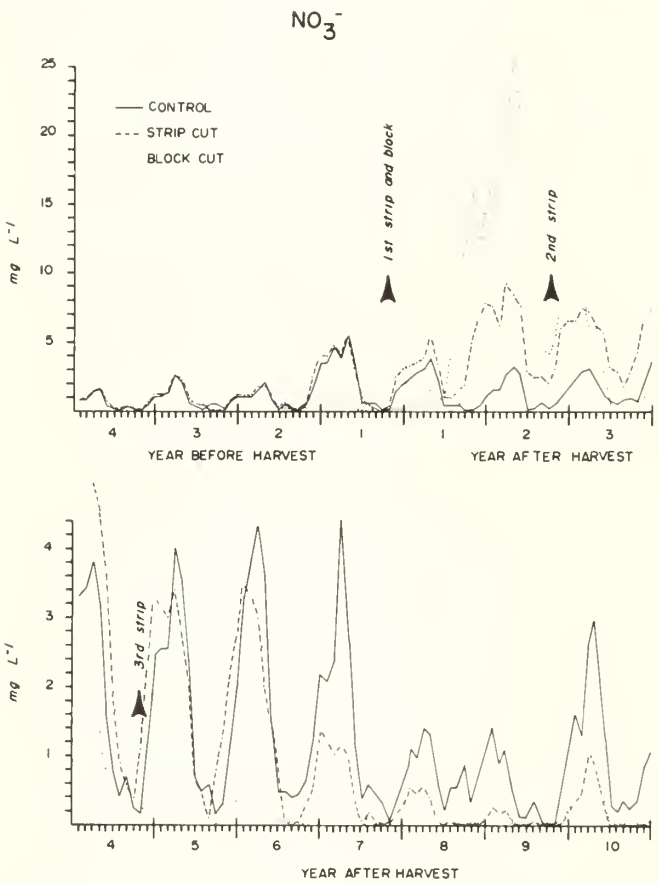

Figure 8.—Weighted, mean monthly NO_3^- in stream water, by calendar year. Note expansion of scale for years 4 through 10 after harvest.

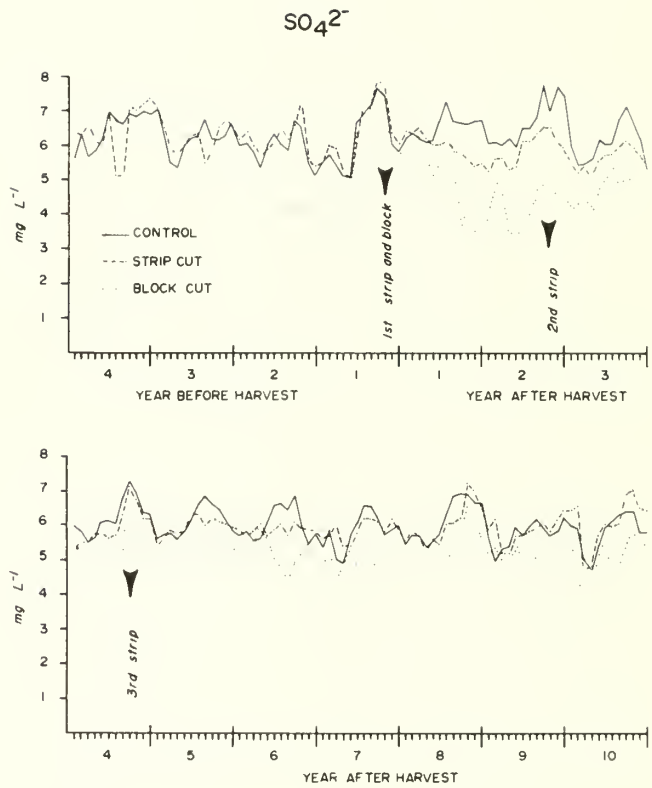

Figure 9.—Weighted, mean monthly SO_4^{2-} in stream water, by calendar year.

were no further changes due to strip cutting. Block cutting caused Cl^- to increase by a maximum of 0.4 mg L^{-1} in the first summer after harvest. This increase also was short lived and was absent by the second summer after harvest.

Cation-anion summary. A comparison of the ionic strength of stream water is a convenient way of summarizing effects due to harvest. Table 3 shows mean annual ion concentrations for year 1 before harvest and for year 2 and year 5 of the harvest period. For year 2 after harvest, when harvest effects were at a maximum, the sum of measured ions for the strip-cut and block-cut watersheds was 16 and 104 percent greater, respectively, than in year 1 before harvest. The same comparison for the control watershed shows a decrease of 7 percent in measured ions. By year 5 of the harvest period, the sum of measured ions had returned to levels found before harvest.

In terms of ion balance, SO_4^{2-}, the dominant anion showed a slight decline in year 2 after both strip and block cutting. However, large increases in NO_3^- resulted in net increases in the sum of anions. The increases in anions were countered by large increases in Ca^{2+} and Mg^{2+} on the strip cut and Ca^{2+}, Mg^{2+}, and K^+ on the block cut. Potassium is the only ion continuing to show an increase at year 5 of the harvest period.

Nutrient Budgets

Changes in stream volume and ion concentrations after strip and block cutting caused streamflow outputs of nutrients to differ from values for uncut forests. For the stream water ions that showed relatively small changes in concentration after harvest, such as Mg^{2+}, Na^+, NH_4^+, and Cl^-, the outputs increased in direct proportion to increases in stream volume. To illustrate, over the 10-year period considered in this paper, streamflows were increased by 4 percent by strip cutting and by 7 percent by block cutting (Table 1). Outputs for the nutrient ions listed previously were increased by about these same percentages. For

Table 3.—Cation-anion relationships in stream water of the study watersheds (values are weighted, annual means)

Item	Ca^{2+}	Mg^{2+}	K^+	Na^+	NH_4^+	H^+	Total cations	SO_4^{2-}	NO_3^-	Cl^-	Total anions	All ions
	ueq L^{-1}											
Strip cut												
Year 1 before harvest	100	35	6	53	2	3	208	133	39	16	188	396
Year 2 after harvest	127	40	8	54	1	5	235	121	87	16	224	459
Year 5 after harvest	94	31	11	49	1	1	187	123	31	12	166	353
Block cut												
Year 1 before harvest	64	34	5	39	1	11	154	115	6	14	135	289
Year 2 after harvest	139	55	21	42	0	14	271	90	211	17	318	589
Year 5 after harvest	71	26	13	33	1	2	146	110	5	11	126	272
Control												
Year 1 before harvest	77	32	6	41	2	14	172	129	34	16	179	351
Year 2 after harvest	69	28	5	37	1	15	155	135	22	15	172	327
Year 5 after harvest	67	27	5	34	1	12	146	127	37	14	178	324

nutrient ions that showed greater changes in concentration, such as Ca^{2+}, K^+, NO_3^-, and SO_4^{2-}, changes in outputs were more variable.

Calcium. The Ca^{2+} budget shows a sizeable net loss under forested conditions (Table 4). The input in precipitation for the 10 postharvest years was 11.5 kg ha^{-1}, while output in streamflow from the watersheds if they had not been cut was estimated as 165.5 kg ha^{-1}. Strip cutting further increased the output by an estimated 26.6 kg ha^{-1}, or 16 percent, while block cutting increased the output by 47.6 kg ha^{-1}, or 29 percent. More than two-thirds of the increase occurred in the first 3 years after initiation of strip cutting, and in the first 2 years after block cutting.

Potassium. The K^+ budget for uncut watersheds also shows a net loss (Table 4). Over the 10 years of study, outputs of K^+ in stream water were increased by 29.6 kg ha^{-1}, or 135 percent, as a result of strip cutting, and 48.0 kg ha^{-1}, or 218 percent, as a result of block cutting. The percentage increases are about 8 times greater than for Ca^{2+}. The changes in outputs were at a maximum in the first few years after harvest, but increases have been consistent throughout the postharvest period.

Nitrate. Nitrate values have been converted to $NO_3 - N$ for the input-output budget summaries. This allows direct comparison of N losses in later discussions about N capital of the study sites. Comparison of inputs in precipitation with outputs if the watersheds had not been cut shows a slight accumulation of $NO_3 - N$ (Table 4). Input over the 10-year study period was 52.9 kg ha^{-1}, and estimated output in the absence of cutting was 45.2 kg ha^{-1}. The substantial variability in annual outputs from undisturbed forests is thought to be related in part to the presence or absence of soil freezing (Likens et al. 1977).

As a result of strip cutting, outputs for the 10 years after harvest were increased by 22.3 kg ha^{-1}, or about 50 percent. Block cutting caused $NO_3 - N$ outputs to be increased by 57.8 kg ha^{-1}, or 128 percent. The largest increases occurred in years 1 through 3 after the start of the strip-cutting sequence, and in years 1 and 2 after block cutting. In years 6 through 10 after strip cutting, and 5 through 10 after block cutting, the harvested watersheds lost smaller amounts of $NO_3 - N$ in streamflow than if they had not been cut.

Sulfate. The $SO_4 - S$ budget shows a net loss on an annual basis (Table 4). The input in precipitation for the 10-year study period was 114 kg ha^{-1} as opposed to an output in streamflow of 185.9 kg ha^{-1} for the forested control watershed. Harvest resulted in relatively small changes, increasing $SO_4 - S$ output by 4.8 kg ha^{-1} after strip cutting, and decreasing $SO_4 - S$ output by 14.0 kg ha^{-1} after block cutting. The small changes indicate that the declines in concentration of SO_4^{2-} ions in streams were mostly compensated for by the increased volume of streamflow.

Table 4.—Annual input-output budgets for Ca^{2+}, K^+, NO_3-N, and SO_4-S, in kg ha^{-1}

Water year after harvest	Input in precipitation	Output if uncut	Changes in outputs due to:	
			Strip cut	Block cut[a]
		Ca^{2+}		
1	1.2	14.9	+7.5*	+21.5
2	1.2	20.2	+6.1*	+11.5
3	2.0	28.3	+7.0*	+2.6
4	1.1	15.8	+1.4*	+0.3
5	0.9	22.3	+0.8	+1.5
6	1.1	13.9	+0.2	+0.5
7	0.8	15.4	+0.8	+2.6
8	0.8	12.2	+1.0	+3.0
9	1.1	10.8	+0.9	+1.6
10	1.3	11.7	+0.9	+2.5
Total	11.5	165.5	+26.6	+47.6
		K^+		
1	0.3	1.9	+1.0*	+9.1
2	0.5	2.5	+2.0*	+6.4
3	0.8	3.0	+4.6*	+6.4
4	0.5	2.1	+1.9*	+2.6
5	0.4	2.4	+4.7*	+5.5
6	0.4	2.0	+3.7*	+4.1
7	0.4	1.9	+3.6*	+4.0
8	0.6	1.9	+2.4*	+3.1
9	0.9	2.2	+2.9*	+3.7
10	0.8	2.1	+2.8*	+3.1
Total	5.6	22.0	+29.6	48.0
		NO_3-N		
1	8.3	8.9	+10.8*	+39.5
2	5.9	4.6	+9.3*	+17.9
3	7.0	8.0	+9.0*	+2.1
4	4.1	4.8	+0.2	0
5	4.6	5.4	+0.4	−0.7
6	5.0	4.8	−2.8	−0.4
7	4.3	1.8	+1.1*	0
8	5.0	1.5	−1.3*	0
9	3.8	2.7	−2.0*	−0.4
10	4.9	2.7	−2.4*	−0.2
Total	52.9	45.2	+22.3	+57.8

Continued

Table 4.—Continued

Water year after harvest	Input in precipitation	Output if uncut	Changes in outputs due to:	
			Strip cut	Block cut[a]
	---------- SO_4-S ----------			
1	10.7	16.1	−1.5*	−1.9
2	14.3	21.3	−0.9	−3.0
3	17.7	27.6	+1.4	−1.3
4	10.3	17.0	+0.8	−0.6
5	11.9	23.4	+2.7*	−0.7
6	10.5	16.3	+2.1*	−1.4
7	10.0	19.1	+0.6	−1.7
8	11.0	16.4	−0.4	−1.1
9	7.4	13.5	−0.1	−1.4
10	10.2	15.2	+0.1	−0.9
Total	114.0	185.9	+4.8	−14.0

* Significant at 0.05 level of probability.

[a] Changes not tested for statistical significant because stream volumes for block cut were estimated by simulation.

Biomass and Nutrients Removed by Harvest

The harvesting operation removed an average of 50 metric t ha^{-1} of biomass from the strip-cut watershed and 65 metric t ha^{-1} from the block clearcut (Table 5). Before cutting, the watersheds were estimated to support 133 and 150 metric t ha^{-1} of aboveground, living, woody biomass, respectively (Whittaker et al. 1974). The removals represent 38 percent of woody biomass from the strip cut watershed and 43 percent of woody biomass from the block cut. The removal efficiency from the strip cut probably is lower because some trees on upper elevation strips were either unmerchantable or were on slopes too steep to log. In such cases the trees were felled, but left in place.

For nutrient removals in harvested products, the rank was Ca > N > K > S > Mg > P (Table 5). Total nutrient element contents of aboveground, woody biomass for Hubbard Brook forests have been estimated by Whittaker et al. (1979) and Likens et al. (1977). When compared with these values, Ca removed in harvest represented 28 percent and 30 percent of aboveground total in woody biomass on the strip-cut and block-clearcut watersheds, respectively. Corresponding values for other nutrients were 26 and 30 percent for K, 31 and 33 percent for Mg, 21 and 25 percent for N, 31 and 35 percent for S, and 18 and 19 percent for P (Table 5).

Regeneration

Natural regeneration has flourished after both block and strip cutting. The density and mix of species changed dynamically in the postharvest period (Table 6). Numbers of stems increased rapidly after harvest and peaked in year 2 at about 1 million stems ha^{-1}. The number of stems for year 2 after harvest reached a maximum on the third set of strips to be cut. This maximum count resulted mainly from increased numbers of herbaceous stems (Table 6), and probably reflects the abundance of seed sources in the previously cut strips.

In terms of ground cover, the vegetation at year 2 after block cutting and each of the strip cuttings formed a dense tangle, averaging about 1.5 m in height. The only areas not revegetated were those under dense slash, or those severely gouged and rutted during logging. Such areas were sampled as part of the regeneration survey and amounted to less than 3 percent of the total watershed area. Dominance in terms of numbers of stems (Table 6) and biomass (Fig. 10) was shared by herbaceous species, especially *Aster acuminatus*, *Dennstaedtia punctilobula*, and *Uvularia sessilifolia*; by species of *Rubus*; by advanced regeneration of *Acer*; and by stump sprouts of *Fagus grandifolia*.

Table 5.—Biomass and nutrient removal in harvested stems

Harvest	Biomass	Ca	K	Mg	N	S	P
	Oven-dry metric t ha^{-1}	---------- *kg ha^{-1}* ----------					
				STRIP CUT			
Preharvest[a]	133	383	155	36	351	42	34
Removed	50	107	40	11	74	13	6
% Removed	38	28	26	31	21	31	18
				BLOCK CUT			
Preharvest[a]	150	466	176	43	392	51	36
Removed	65	139	52	14	97	18	7
% Removed	43	30	30	33	25	35	19

[a] From Whittaker et al. (1974, 1979) and Likens et al. (1977).

Between years 2 and 10 the canopy closed and tree species gained dominance in both height and biomass (Fig. 10). Although the ratio between total numbers of trees, herbs, and shrubs showed no drastic changes, competition reduced total stems at year 10 to several hundred thousand ha^{-1} (Table 6). Also by year 10, some tree species had achieved sufficient diameter growth to move into the lower diameter classes (Table 7). The three most common northern hardwood species, *Betula alleghaniensis*, *Acer saccharum*, and *Fagus grandifolia*, became prominent in terms of total numbers of stems by year 10. *Prunus pensylvanica*, an exploitive species (Bormann and Likens 1979), occurred in moderate numbers on the strip cutting and in large numbers on the block cutting, and usually dominated in terms of biomass as a result of having far more stems in the larger diameter classes (Table 7).

Total biomass was between 34 and 53 metric t ha^{-1} at 10 years after the cuttings (Table 8). These values represent 25 to 40 percent of the aboveground biomass before harvest. As mentioned previously, most of the biomass at 10 years was dominated by tree species, especially *Prunus pensylvanica*. For example, on the block clearcutting, the 51 metric t ha^{-1} of biomass at year 10 (Table 8) consisted of 29 t ha^{-1} of *Prunus pensylvanica*, 11 t ha^{-1} of *Betula alleghaniensis*, 4 t ha^{-1} of *Fagus grandifolia*, and 2 t ha^{-1} of *Acer saccharum*. The biomass for *Prunus pensylvanica* actually was beginning to show a decline, having peaked at 31 t ha^{-1} at year 7 after harvest. This decline is in line with the usual growth pattern followed by *Prunus pensylvanica* (Bormann and Likens 1979).

Discussion

Changes in Water Yield

The most important effect of strip and block cuttings on water yield at Hubbard Brook included:

1. Increases in annual water yield, most of which occurred in the growing season months of June through September.

2. Changes in timing of spring flows due to a speedup in snowmelt on the harvested watersheds.

These are the same effects that occurred after an earlier experiment on Hubbard Brook Watershed 2, which was clearfelled and then treated with herbicides (Hornbeck et al. 1970). In that experiment, for a 3-year period in which vegetation was controlled with herbicides, annual increases in streamflow averaged 288 $\pm$ 54 mm. For the first water year after the block clearcutting, the simulated increase in water yield was a comparable 278 mm (Table 1). For the first year after strip cutting, with only one-third of the watershed harvested, the increase in water yield was 22 mm.

The increases in water yield from the strip-cut watershed were not as large as might have been anticipated. Hibbert (1967) and Douglass and Swank (1972) suggest that for the Eastern United States, increases in water yield for the first year after forest cutting are roughly proportional to percentage reduction in basal area. Thus, increases in water yield

Table 6.—Number of trees, shrub, and herbaceous stems at 2 and 10 years after individual harvests (elevation ranges are low, 440 to 550m; mid, 550 to 650m; and high, 650 to 750 m; block cut spanned elevations 470 to 600 m, or closest to mid-elevation range on strip cut)

Species	First strip						Second strip						Third strip						Block cut	
	Low		Mid		Upper		Low		Mid		Upper		Low		Mid		Upper		Mid	
	Year 2	Year 10	Year 2	Year 10	Year 2	Year 10	Year 2	Year 10	Year 2	Year 10	Year 2	Year 10	Year 2	Year 10	Year 2	Year 10	Year 2	Year 10	Year 2	Year 10
	Thousands of stems ha^{-1}																			
Tree[a]	593	132	521	99	221	89	253	54	282	49	155	40	428	74	310	49	198	67	661	231
Shrub[b]	165	53	32	92	93	220	111	16	130	27	76	55	204	11	216	20	117	67	51	33
Herbaceous[c]	340	282	733	226	535	622	501	129	463	90	338	228	832	195	1160	108	772	542	297	183
All species	1098	467	1286	417	849	931	865	199	875	166	569	323	1464	280	1686	177	1087	676	1009	447

[a] Major tree species include: *Abies balsamea*, *Acer pensylvanicum*, *A. rubrum*, *A. saccharum*, *A. spicatum*, *Betula alleghaniensis*, *B.papyrifera*, *Fagus grandifolia*, *Fraxinus americana*, *Picea rubens*, *Populus spp.*, and *Prunus pensylvanica*.

[b] Major shrub species include: *Rubus spp.*, *Sambucus canadensis*, and *Viburnum alnifolium*.

[c] Major herbaceous species include: *Aster acuminatus*, *Dennstaedtia punctilobula*, *Dryopteris spinulosa*, *Lycopodium lucidulum*, *Maianthemum canadense*, *Oxalis montana*, *Trillium spp.*, *Uvularia sessilifolia*, and *Viola spp.*

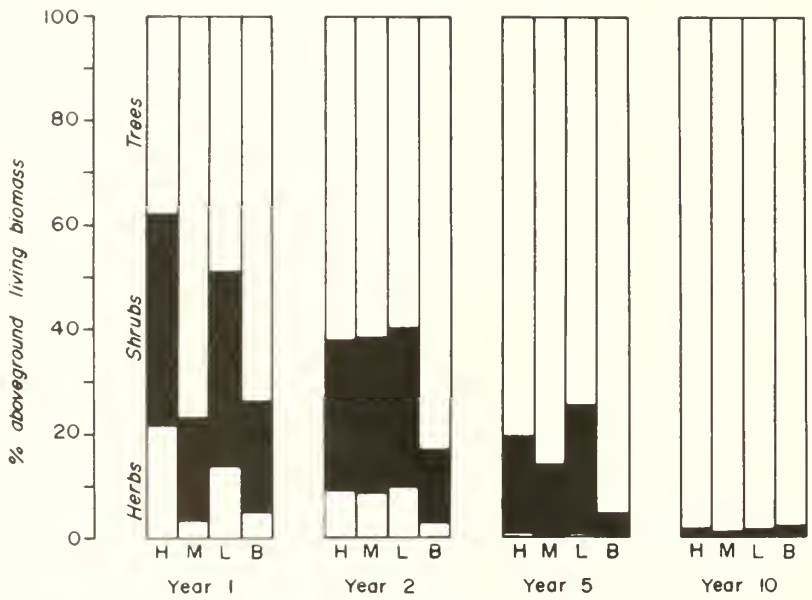

Figure 10.—Proportions of biomass occupied by trees, shrubs, and herbs on the second strip (H, M, and L are high-, medium-, and low-elevation zones) and the block clearcut (B).

after cutting the first set of strips may have been expected to be about 90 mm, or one-third of that occurring from that block cutting. The actual yield increase in year 1 from the strip cutting was less than one-tenth that from the block cut. And increases through the 10 postharvest years from the strip cuts were only 60 percent of those from the block cut (Table 1).

The explanation for the smaller than anticipated increases lies in the cutting configuration. A strip cut increases the crown exposure and transpiration rate of the residual trees that border the cut strips (Federer and Gee 1974). A portion of the added transpiration may be drawn from the extra water available in the cut strips, or from soil water moving downslope from cut into uncut strips. As a result, increases in streamflow are smaller than they would have been if the area had been cut in one large block. The larger increases for the first water year after cutting of the second and third sets of strips (Table 1) support this explanation.

Thus, it appears that strip cutting compared with block cutting is an inefficient form of forest harvest if augmentation of water yield is the most important consideration. The increases are small in relation to total area cut over. On the other hand, the smaller increases in water yield mean that there is less opportunity for nutrients to be transported from the watershed in dissolved and particulate forms.

Regarding the changes in timing of streamflow during snowmelt, the advances in snowmelt runoff that occurred after strip and block cutting were sizeable. However, when cutting is a small portion of a larger watershed, these advances quickly become unrecognizable when joining with streams from completely forested areas (Hornbeck and Pierce 1969). If the timing changes after cutting are to have a practical significance with regard to downstream flooding, thousands of hectares within individual, regional watersheds would have to be harvested. There seems little likelihood that clearcutting will ever be of sufficient scale in New England to bring about significant changes in downstream spring floods.

The rate at which water yield returns to preharvest levels should be strongly correlated with regrowth of vegetation. This is illustrated for the block clearcut by plotting annual increases in water yield in relation to increases in stand biomass (Fig. 11). Increases in water yield declined steadily with accumulating biomass, and were minimal when biomass reached 50 metric t ha^{-1}, or about one-third of the biomass found before harvest.

Erosion Losses in Streamflow

For undisturbed forests at Hubbard Brook, losses of nutrient elements via streamflow are greater in dissolved form than in sediment or particulate form (Bormann et al. 1969, 1974). The ratio for individual elements varies, but in terms

Table 7.—Stems ha^{-1}, by diameter class, for six major tree species occurring at year 10 after harvest

Species	Elevation	First strip				Second strip				Third strip				Block clearcut			
		D.b.h. class				D.b.h. class				D.b.h. class				D.b.h. class			
		<2.5	2.5-4.9	5.0-7.5	7.6-9.9	<2.5	2.5-4.9	5.0-7.5	7.6-9.9	<2.5	2.5-4.9	5.0-7.5	7.6-9.9	<2.5	2.5-4.9	5.0-7.5	7.6-9.9
		Stems ha^{-1}															
Betula alleghaniensis	Low	25,300	743	57	0	3,800	1,467	200	67	8,800	2,067	467	0				
	Mid	19,000	560	80	0	1,200	2,467	267	0	1,800	1,600	743	114	144,000	1,450	42	8
	Upper	23,500	629	171	57	5,000	3,257	229	0	13,700	2,333	267	0				
Acer saccharum	Low	36,800	57	0	0	27,500	2,533	333	67	37,500	1,200	67	0				
	Mid	45,500	240	80	0	24,600	1,533	267	0	25,000	1,829	229	0	16,800	341	17	0
	Upper	18,900	343	0	0	12,800	0	0	0	10,400	67	0	0				
Fagus grandifolia	Low	5,400	343	57	0	4,200	1,067	67	0	7,500	933	0	0				
	Mid	9,000	160	0	0	5,400	2,533	0	0	4,600	629	57	57	14,300	434	0	8
	Upper	7,600	571	0	0	2,500	914	171	57	9,600	1,200	67	0				
Prunus pensylvanica	Low	9,600	1,943	1,029	286	0	150	600	333	0	933	600	467				
	Mid	1,000	2,000	1,440	320	2,500	1,467	1,113	57	0	400	400	171	17,900	6,375	1,183	67
	Upper	1,800	857	171	171	2,800	1,029	514	57	1,700	200	133	0				
Acer pensylvanicum	Low	4,700	686	400	0	2,100	867	0	0	4,600	733	133	0				
	Mid	8,000	560	80	0	1,300	1,667	133	0	5,000	1,086	57	0	9,500	250	0	0
	Upper	5,000	0	0	0	5,400	229	57	0	10,000	133	0	0				
Acer spicatum	Low	5,000	229	0	0	2,100	2,067	267	0	0	133	0	0				
	Mid	0	0	0	0	0	400	0	0	3,200	229	0	0	300	8	0	0
	Upper	12,200	0	0	0	1,800	343	0	0	7,100	0	0	0				

Table 8.—Aboveground, living biomass at various years after strip cutting and block clearcutting

Year after harvest	First strip	Second strip	Third strip	Block clearcut
	Metric t ha^{-1}			
1	1	2	3	2
2	6	4	6	16
3	8	6	NA	24
4	12	10	9	NA
5	13	NA	NA	35
10	34	53	42	51

of gross export of mass, dissolved substances average about 165 kg ha^{-1} yr^{-1}, or about 5 times the amount lost in sediment or particulate form (Likens et al. 1977).

Our study did not determine sediment losses directly. However, the very small changes in the many turbidity readings obtained during and after harvests (Table 2) and in the material trapped in the weir basins indicate minimal changes in sediment or particulate losses resulting from harvest.

Of the two harvested watersheds, the block clearcut was thought to have the greater potential for erosion losses. Increases in water yield were greater after block clearcutting, increasing the chances for streambank and channel erosion, and no buffer strip was left. However, the turbidity data (Table 2) indicate that erosion losses after the block clearcut remained at the same low levels as from the strip cutting. The results confirm an earlier conclusion from the clearfelling and herbicide experiment on Hubbard Brook Watershed 2 (Bormann et al. 1974): northern hardwood ecosystems have an inherent resistance to erosion that can withstand cutting disturbances so long as the forest floor is not abused.

To protect the forest floor and maintain low erosion losses, known precautions were taken during logging. For example, logging was conducted in early autumn when chances for erosion and sedimentation are least. A buffer strip of trees was left along the stream channel in the strip cut, and efforts were made to avoid streamside zones in both the clearcut and strip cut. Skidroads were kept at lowest possible grades, and water bars were installed. These efforts, together with rapid revegetation, prevented serious erosion and resulted in minimal changes in nutrient losses in suspended or particulate form, and preservation of the high quality of forest streams at Hubbard Brook.

Concentrations of Stream Water Ions

The changes in concentration of various stream water ions during our study paralleled those reported for other studies in northern hardwood stands in New England. The increases in Ca^{2+}, K^{+}, Mg^{2+}, and NO_3^{-} and decreases in SO_4^{2-} occurred after clearfelling and herbicide applications on Hubbard Brook Watershed 2 (Likens et al. 1970); after clearcuttings in the White Mountains of New Hampshire (Pierce et al. 1972; Martin and Pierce 1980); after a variety of clearcuttings located in Maine, New Hampshire, and Vermont (Martin et al. 1984); and after a whole-tree harvest in New Hampshire (Hornbeck and Kropelin 1982). The causes of the changes in concentrations are reasonably well understood, though not completely quantified.

Mechanisms affecting concentrations. Several mechanisms may be responsible for the changes in ion concentrations after harvest.

1. Blocking of uptake. Uptake of available nutrients by living vegetation can be sizeable. For example, annual uptake of Ca^{2+} by Hubbard Brook forests is estimated at 62 kg ha^{-1} (Likens et al. 1977). Clearcutting temporarily blocks uptake while decomposition goes forward and increases the amount of available nutrients in the dissolved inorganic fraction of the soil solution. The greater amounts of soil water resulting from reduced interception and transpiration provide a means of transport to streams. Calcium

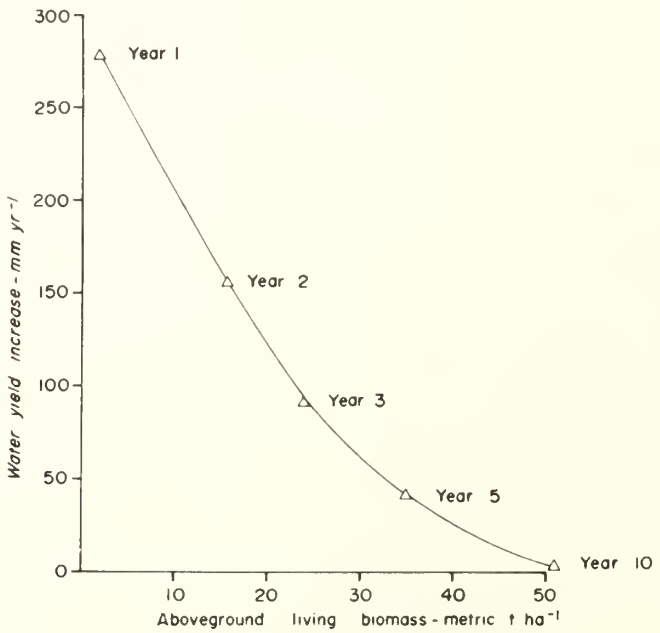

Figure 11.—Relationship of annual increases in water yield (the curve is hand-fitted).

probably is the best example of this mechanism, increasing to maximums in the first 1 to 2 years after harvest, then declining with regrowth (Fig. 5). Potassium shows this same pattern initially (Fig. 6), but does not fully decline with regrowth, indicating that other mechanisms are involved.

The decline with regrowth may involve other mechanisms. For example, in the Hubbard Brook Watershed 2 experiment in which the area was kept free of vegetation for 3 years, declines in concentrations began in the third year without revegetation. This suggests that exhaustion of easily decomposed substrate also plays a role in decreases in ion concentrations.

2. Critical element shunt. This mechanism is proposed by Bormann and Likens (1979) to operate as follows: in the first year after harvest, when C:N and element:P ratios of decaying organic matter are high, dissolved nutrients in soil solution are taken up by the increased numbers of microorganisms. As the C:N and element:P ratios decrease, and demands by microorganisms decline, nutrient ion export to streams increases. The critical element shunt may explain why nutrient ion concentrations are highest in the second year after harvest (Figs. 5, 6, 8, 9).

3. Accelerated nitrification. Nitrification rates in soils of undisturbed forests in New England are low, seldom exceeding 3 kg ha^{-1} mo^{-1} during the growing season (Federer 1983). However, the nitrification rate increases dramatically after cutting of northern hardwoods (Likens et al. 1970; Vitousek and Melillo 1979). The result is a flush of available NO_3^- and H^+, and, in turn, a mobilization of cations. The transport to streams is rapid, as indicated by the quick response of stream NO_3^- to cutting (Fig. 8). The fact that NO_3^- concentrations in streams fell below preharvesting levels in the fifth or sixth year of regrowth suggests several possibilities, including a corresponding decline in nitrification rates to levels below those in undisturbed forests, a greater uptake of N by the rapidly growing new stand, increased immobilization of N by soil organisms, or an increase in denitrification. These possibilities have not been tested for our study areas.

4. Accelerated decomposition of organic matter. Canopy removal exposes the forest floor and mineral soil to greater amounts of light, heat, and moisture, and accelerates decomposition and mineralization of organic materials (Bormann and Likens 1979). Covington (1981) showed that the forest floor in northern hardwood stands declines by about 50 percent in weight, or an average of 31 t ha^{-1} in the 15 years after clearcutting. One-third of this decline was estimated to occur in the first 3 years following cutting. During the 15-year degrading phase, it was estimated that net nutrient releases from mineralization of forest floor material were 35 kg Ca ha^{-1}, 31 kg Mg ha^{-1}, 44 kg K ha^{-1}, and 808 kg N ha^{-1}. These releases are a source for increased ion concentrations of soil water and streams.

5. Accelerated weathering of inorganic materials. Compared to decomposition of organic matter, weathering of mineral soil and rocks generally is a less active source of nutrients at Hubbard Brook (Likens et al. 1977). The increased exposure to heat and moisture that accelerates decomposition also should speed weathering rates, though this effect has not been quantified.

While these mechanisms occur after both strip and block cutting, increases in concentrations of stream ions due to strip cutting were less than one-third of those for block cutting. The small responses after strip cutting can be explained in part by mobile ions being intercepted and used by uncut or regenerating strips or the stream buffer zone. Also, the strip-cutting configuration should reduce decomposition and weathering by better protecting the cut sites from light and excessive heat. Thus, the availability of nutrients for leaching from the cut strips would be less than in the larger opening created by block clearcutting. Although the increases were smaller after strip cutting, the progression of three harvests caused them to last up to 2 to 3 times longer than increases after the block clearcutting.

Sulfate. A variety of hypotheses have been suggested for explaining the decrease in concentrations of SO_4^{2-} in streams after cutting. After the clearfelling of Hubbard Brook Watershed 2, Likens et al. (1970) attributed the decreases in SO_4^{2-} partly to dilution by the increased water yields and partly to the reduction of SO_4^{2-} generation by sources internal to the ecosystem. Fuller et al. (1986) suggested the same hypotheses for streams from a whole-tree harvest at Hubbard Brook and added the possibilities of decreased dry deposition and increased SO_4^{2-} adsorption by soils. Regarding this latter possibility, Nodvin (1983) proposed that excess acid production by elevated nitrification rates increases the net positive charge on soil surfaces, and enhances adsorption of SO_4^{2-} ions. The theory was tested in the laboratory and found applicable for the Hubbard Brook Watershed 2 experiment involving clearfelling and herbicides, and would seem equally applicable for the strip-cut and block-clearcut watersheds.

Hydrogen. Changes in H^+ are of special interest in relation to effects of acid precipitation. The forest canopy at Hubbard Brook at least temporarily reduces H^+ in precipitation from 0.08 mg L^{-1} above the canopy to 0.01 mg L^{-1} beneath (Eaton et al. 1973). Felling of the canopy during harvest allows acid precipitation to fall directly on soils and streams and possibly have more impact. Also, as mentioned earlier, the increased nitrification rates accompanying harvest are acidifying and could combine with acid precipitation to accelerate acidification of soils and streams. The amount of H generated by this mechanism is substantial. Based on output of $NO_3 - N$ in stream water, increased nitrification in the first year after harvest resulted in H production of 2.8 kg ha^{-1} on the block clearcut and

0.6 kg ha^{-1} on the strip cutting. These values can be compared with the average annual input of H^+ in precipitation of 1.0 kg ha^{-1} (Likens et al. 1977) and the annual total of 2.5 kg ha^{-1} generated by all H^+ sources within an undisturbed Hubbard Brook watershed (Driscoll and Likens 1982).

Thus, it is not surprising that there were small increases in stream water H^+ of 0.001 - 0.002 mg L^{-1} after strip cutting and 0.004 mg L^{-1} after block clearcutting (Fig. 7). The increases were short lived, and after year 2 of the block clearcut, the H^+ fell 0.008 mg L^{-1} below preharvest levels. Such changes are barely detectable and any impacts on stream chemistry and biota would be extremely difficult to quantify. Concerns should not be totally dismissed as changes in H^+ of soils and soil solution could be more pronounced and of greater significance than those occurring in streams (Federer and Hornbeck 1985).

Management implications. Changes in concentrations of nutrient ions in streamflow raise at least three concerns: (1) importance as a loss from site nutrient capital, (2) potential for harming water quality, and (3) adverse or beneficial effects on stream biota. A later section relates the importance of dissolved ions to nutrient capital. Regarding water quality, no measured ion concentrations exceeded standards or guidelines established for protecting water for domestic or recreational use. Nitrate came closest, reaching a maximum of 26 mg L^{-1} after block clearcutting versus the established standard of 45 mg L^{-1} for drinking water. Relationships of changing ion concentrations to stream biota have had only minimal study. Noel et al. (1986) and Likens et al. (1970) reported increases in stream periphyton and macroinvertebrates after clearcutting northern hardwoods, but they did not separate effects of stream chemistry from those of light and temperature. Where there is concern about stream biota or water quality, our study shows that changes in stream ions resulting from even-age management practices can be moderated substantially by using strip cutting rather than block clearcutting.

Evaluation of Nutrient Removals and Leaching Losses

Nutrient removals and leaching losses for the strip-cut and block-clearcut watersheds are summarized in Table 9. The table also shows nutrient pools, which serve as one basis for evaluating the importance of nutrient removals and losses. Such evaluations are not straightforward as there are still many unknowns. To illustrate, Figure 12 shows hypothetical curves of nutrient fluxes that would have to be quantified to fully evaluate harvest effects on site productivity. Such data would be needed for all nutrients likely to become growth limiting, and for stages of stand development beyond the critical 10-year regeneration period shown in Figure 12. While forest ecosystem studies at many locations are gradually providing these kinds of data and information, detailed evaluations of harvest impacts cannot yet be made.

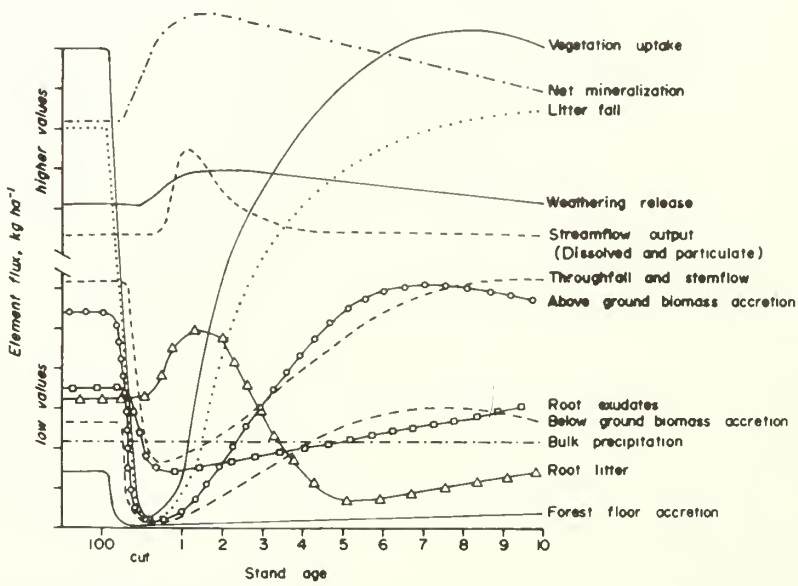

Figure 12.—Hypothetical curves of changes in fluxes of nutrient elements, such as Ca, K, and Mg, in years 1 through 10 after harvest.

Table 9.—Summary of nutrient removals, leaching losses, and nutrient pools

Item	Ca		K		Mg		N		S		P	
	Strip cut	Block clearcut	Strip cut	Block clearcut	Strip cut	Block clearcut	Strip cut	Block clearcut	Strip cut	Block clearcut	Strip cut	Block clearcut
	kg ha⁻¹											
Removal by harvest	107	139	40	52	11	14	74	97	13	18	6	7
10-year dissolved ion losses in streamflow attributed to harvest	27	48	30	48	3	7	22	58	5	−14	0[e]	0[e]
Total losses due to harvest	134	187	70	100	14	21	96	155	18	4	6	7
	Estimated Preharvest Nutrient Pools, *kg ha⁻¹*											
Vegetation	383[a]		155[a]		36[a]		351[a]		42[a]		35[e]	
Roots	101[a]		63[a]		13[a]		181[a]		17[a]		29[e]	
Forest floor	372[a]		66[a]		38[a]		1100[a]		124[a]		57[e]	
Mineral soil:												
Available	510[a]		75[c]		41		26[d]		NA		NA	
Total[f]	9600[a]		5084[c]		7659		3600[d]		560[a]		2524[e]	
Total	10,456		5368		7746		5232		743		2645	
	Control Watershed, *kg ha⁻¹ yr⁻¹*											
Dissolved ion input precipitation	1.7[b]		0.8[b]		0.5[b]		6.5[b]		11.9[b]		.04[e]	
Dissolved ion output streamflow	12.5[b]		1.9[b]		2.9[b]		3.7[b]		17.2[b]		.02[e]	
Net	−10.8[b]		−1.1[b]		−2.4[b]		2.8[b]		−5.3[b]		.02[e]	
Weathering release	21.1[a]		7.1[a]		3.5[a]		0[d]		0.8[a]		1.5[e]	
Net mineralization	42.6[a]		20.1[a]		6.1[a]		69.6[d]		5.7[a]		10.6[e]	

[a] Likens et al. (1977) and Whittaker et al. (1979).
[b] Mean for 1963 through 1981.
[c] Hornbeck and Kropelin (1982).
[d] Bormann et el. (1977).
[e] Wood (1980) and Wood et al. (1984).
[f] Includes available soil elements.

In the interim, several studies have evaluated nutrient removals and leaching by comparing them with both plant-available and total nutrient capitals of the harvest site (Freedman et al. 1981; Weetman and Webber 1972; Weetman and Algar 1983; Johnson et al. 1982; Hornbeck and Kropelin 1982). At least two of these studies point out that a more realistic value for such comparisons, and one that might ultimately prove useful to forest managers, lies somewhere between available and total capitals (Freedman et al. 1981; Hornbeck and Kropelin 1982).

In the evaluations that follow we compare nutrient removals and leaching losses with both available and total nutrient capitals. We used an approach developed by Bormann and Likens (1979) that incorporates some of the more important nutrient fluxes from Figure 12. This approach can be used only for the first 4 years after harvest as data are not yet available for additional years. Even so, evaluations now are far more thorough than was possible at the height of the clearcutting controversy in the early 1970's.

Calcium. Before harvest, estimated total and available capitals for Ca were 10,456 and 510 kg ha^{-1} respectively (Table 9), the largest values for any of the nutrient elements studied. Losses of Ca of 134 kg ha^{-1} due to strip cutting and 187 kg ha^{-1} due to block clearcutting (Table 9) represent 1.3 and 1.8 percent of total site nutrient capital, and 26 and 37 percent of available capital. The nutrient losses obviously are more impressive as proportions of available capital than of total capital. The major concern would seem to be that the available pool does not become limiting to regrowth during present and future rotations.

Using the approach from Bormann and Likens (1979), we compared some of the major fluxes of available Ca in the years immediately following harvest. The sum of Ca^{2+} losses in stream water plus Ca stored in regrowing biomass ranged from 45 to 61 kg ha^{-1} yr^{-1} the first 4 years after block clearcutting (Fig. 13). Mineralization of Ca from the forest floor (Covington 1981) could supply as much as one-third of the Ca^{2+} needed to satisfy streamwater losses and storage in biomass. The remainder, or at least 25 to 40 kg ha^{-1} yr^{-1}, may have to be drawn from other sources, especially mineral soil. The available pool in the mineral soil is maintained by several processes including weathering, which supplied 21 kg Ca^{2+} ha^{-1} yr^{-1} before harvest (Table 9), and should supply even greater amounts immediately after harvest. Mineralization in the mineral soil also should supply increased amounts of available Ca^{2+} after harvest. As another source, logging slash contains more than 200 kg ha^{-1} of Ca^{2+}, some of which should mineralize quickly in the years after harvest. Thus, it seems that at least initially there should be no major decline in the available pool. There are mechanisms to adequately replace stream water losses and biomass storage.

Potassium. The preharvest pools for K were estimated at 5,368 kg ha^{-1} for total capital and 75 kg ha^{-1} for available (Table 9). The combined losses due to harvest of 70 kg ha^{-1} for strip cutting and 100 kg ha^{-1} for block clearcutting represent 1.3 and 1.9 percent of the total capital and 93 and 133 percent of available. Concerns about K losses in relation to the available pool may be even greater than for Ca.

In the 4 years immediately after block clearcutting, the sum of K^+ losses in stream water plus K stored in biomass showed a linear increase (Fig. 13). Since estimated mineralization of K from the forest floor is relatively constant immediately after harvest (Covington 1981), contributions of K from other sources become increasingly more important with time. Combined mineralization and weathering before harvest were estimated to contribute 27 kg K ha^{-1} yr^{-1} to the available pool. As with Ca, there would seem to be a continued, adequate pool of available K after harvest. However, in contrast to Ca, increased losses of K^+ in stream water have not subsided completely. Continued evaluation will be required as more data are obtained.

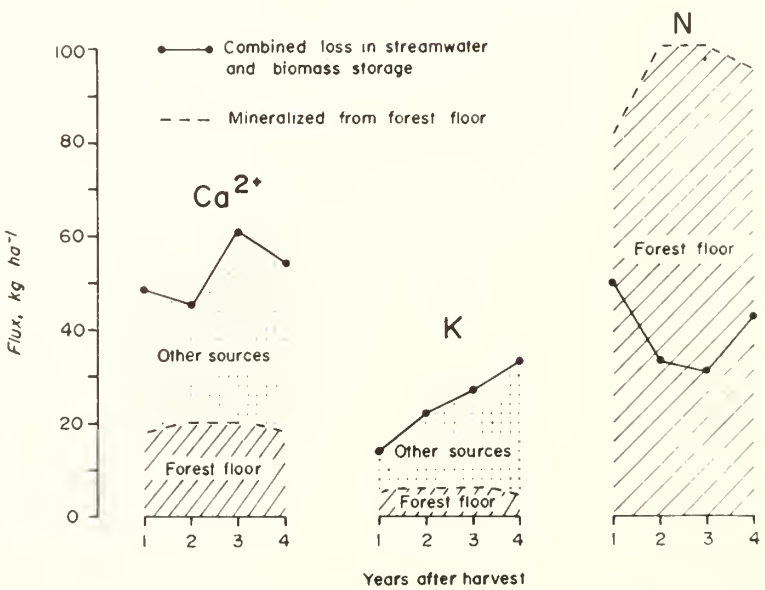

Figure 13.—Nutrient flux and sources in the initial 4 years after block clearcutting. Data on forest floor and biomass storage from Bormann and Likens (1979).

Magnesium. Magnesium pools before harvest were 7,746 kg ha^{-1} total and 41 kg ha^{-1} available (Table 9). Total losses due to strip cutting were 14 kg ha^{-1} or 0.2 percent of total and 34 percent of available. For block clearcutting, losses were 21 kg ha^{-1} or 0.3 percent of the total and 51 percent of available. The proportionally smaller losses for Mg compared with K reflect a tighter nutrient cycle for Mg. For undisturbed forests, combined weathering and mineralization for Mg is estimated at about 10 kg ha^{-1} yr^{-1} (Table 9). It seems unlikely that the Mg losses due to harvest would adversely affect regrowth. The losses of Mg are small and the reserve pool is large, and increased losses of Mg^{2+} in streamflow did not last beyond the second growing season after harvest.

Nitrogen. Nitrogen is of special interest because of concerns that it may be limiting to plant growth, even before harvest. Losses due to harvest of 96 kg ha^{-1} from the strip cut and 155 kg ha^{-1} from the block clearcut represent 1.8 and 3.0 percent of the estimated total capital of 5,232 kg ha^{-1} (Table 9). In terms of available capital of 26 kg ha^{-1}, the losses represent 369 percent for strip cutting and 596 percent for block clearcutting.

In contrast to Ca^{2+} and K^{+}, estimated mineralization of N from the forest floor after harvest is more than double the combined loss in stream water plus storage in biomass (Fig. 13). The fate of N lost from the forest floor is uncertain, but translocation to mineral soil and denitrification are possibilities (Bormann and Likens 1979). There have been large increases in NO_3^- in soil solution of mineral horizons after harvest of northern hardwoods (Hornbeck and Kropelin 1982), but it is not clear if the increases resulted from translocation out of upper horizons or from localized nitrification. The evaluation of denitrification has only recently been initiated at Hubbard Brook as part of a whole-tree harvesting experiment.

Increased nitrification and decomposition of the forest floor should provide adequate supplies of available N for regrowth immediately after harvest. However, there is some question as to whether available N is sustained through the regrowth period. To illustrate, Hornbeck and Kropelin (1982) found that NO_3^- in mineral soil solution increased 25-fold in the first 2 years after a whole-tree harvest of northern hardwoods. However, NO_3^- concentrations then declined rapidly, and by the fourth year after harvest were at levels below those in undisturbed forests. This pattern was similar in streamflow after harvest of our study watersheds at Hubbard Brook, indicating a potential for critical levels of available N by 4 to 5 years after harvest. Covington and Aber (1980) suggested that limited N at years 6 to 11 after clearcutting may be responsible for a decline in leaf production found in the exploitive species, *Prunus pensylvanica*. More research is needed on the N cycle to fully evaluate impacts on regrowth.

Losses of N resulting from harvesting may be replaced in part from atmospheric sources. The inputs of N in precipitation exceed outputs in streams by an average of about 3 kg ha^{-1} yr^{-1} (Table 9). Also, the only positively identified substrate for fixation of atmospheric N at Hubbard Brook is deadwood more than 2 cm in diameter (Roskoski 1980). Large amounts of this size material were left as slash on the harvested watershed. Roskoski (1980) estimated that about 2 kg N ha^{-1} yr^{-1} may be fixed in this material at year 4 after clearcutting.

Finally, there seems to be a mechanism for minimizing leaching losses of N after harvest. As shown in Figure 8 and Table 6, N losses in streamflow at 5 to 6 years after completion of harvest fell below those for undisturbed forests. Depending on how long this effect lasts, and assuming that N is not being lost in some other, unknown manner such as denitrification, N losses after harvest could be replaced by atmospheric sources in as little as 20 to 30 years. At the average net gain of 2.8 kg ha^{-1} for undisturbed forests (Table 9), the replacement time would be 34 to 55 years. This period could be even shorter if N fixation is found to be greater, a possibility suggested by the calculated mass balance of N for Hubbard Brook (Bormann et al. 1977).

Sulfur. Harvesting removed relatively small amounts of S and had little effect on S lost in stream water (Table 9). Sulfate-S occurs in high concentrations in streams (Fig. 9) and in soil solution (Hornbeck and Kropelin 1982) in our study area, both before and after harvest, and there is no apparent reason for concern about availability of S during regrowth.

Phosphorus. Removals of P in harvested products represented 0.2 percent of the preharvest P capital (Table 9). On the basis of research by Wood et al. (1984), we estimated that strip and block cutting did not increase losses of P in streamflow.

Total losses of P to harvest are small compared with the overall site capital. However, harvest may cause an important redistribution of soil P. Wood et al. (1984) point out that P is biologically conserved in the surface soil horizons of undisturbed forests at Hubbard Brook by the close coupling between decomposition and uptake. They suggest that harvest disrupts biological control of P and allows large amounts of P to move downward from the forest floor to B horizons. The time required to restore the P that moved from the forest floor is unknown.

Management implications. Overall, the nutrient losses resulting from strip cutting and block clearcutting at Hubbard Brook do not seem a major concern. Combined losses to increased leaching and product removal did not exceed 3 percent of total capital for any of the nutrients

studied. In terms of available capital, the losses were more impressive, ranging from 26 to 596 percent. However, it appears that replacement mechanisms will be able to maintain the available pools at adequate levels. Nitrogen and K may be exceptions, particularly beyond the fifth year of regrowth. We are continuing to monitor K losses, and the nitrogen cycle is a central focus of a whole-tree harvest study in progress at Hubbard Brook.

Losses to harvest were less for strip cutting than for block clearcutting (Table 9)—partly because strip cutting moderated leaching losses, and partly because less material was harvested from the strip cut (Table 5). Management prescriptions for these watersheds call for harvesting again for sawtimber is not less than 70 years, and more likely in about 110 to 120 years (Leak et al. 1969; Solomon and Leak 1969). This should be adequate time to replenish the nutrients and organic matter lost as a result of harvest (Likens et al. 1978).

While the actual nutrient removals and increased leaching losses may not be a problem, transformations and redistribution of nutrients remaining on site could affect regrowth. As discussed, N may become limiting around year 5 of regrowth when nitrification declines to very low levels. The redistribution of P from organic to mineral soil also could affect regeneration. Strip cutting might moderate some of these effects, but more information is needed.

Regarding nutrient removals in harvested products, although our study watersheds were completely clearcut, the use of biomass was not intensive by current standards. The increasing use of newly designed, mechanized logging and processing equipment, and rising demands for wood as pulp and an energy source, have greatly increased biomass harvesting. Nutrient removals for whole-tree harvesting of northern hardwoods may be 2 to 3 times the values reported here (Hornbeck 1977; Hornbeck and Kropelin 1982). In such cases, and especially when coupled with projections for significantly shorter period betwen harvests, nutrient removals may be of much greater concern.

Regeneration

Regeneration on both the strip and block cuts is following the pattern outlined by Bormann and Likens (1979). Outgrowth, or occupation of the sites by exploitive and existing species, especially herbs and shrubs, peaked at about year 2 after harvest (Table 6). By year 10, upgrowth by tree species was well along and a closed canopy had formed. Dominant species at 10 years were *Prunus pensylvanica* and the three major northern hardwoods, *Betula alleghaniensis, Acer saccharum,* and *Fagus grandifolia. Prunus pensylvanica* usually dies at about 30 years, by which time the stands should be wholly dominated by northern hardwood species.

As mentioned at the outset, a prime objective of strip cutting is to regenerate high proportions of *Betula* and *Acer* in the new stand. It is difficult at this stage of regrowth to evaluate whether strip cutting has resulted in a more desirable species mix than block clearcutting. Little is known about what the species composition and stocking levels must be at age 10 to produce a commercially valuable northern hardwood stand. Strip cutting certainly appears successful in terms of total stems. *Betula alleghaniensis* and *Acer saccharum* were the most frequently occurring tree species on the strips at age 10 (Table 7).

Species composition differed markedly among the sets of strips (Table 10), partly because of environmental factors such as light, temperature, and moisture, and partly because of abundance of seed. Through year 10, stand development was optimum on the second and third strips, which had a favorable mix of species, especially in the 2.5–4.9, and 5.0–7.5 cm d.b.h. classes, and fewer *Prunus*

Table 10.—Species densities for trees more than 2.5 cm d.b.h. on harvested and control watersheds; observations for the strips and control stand are for the middle elevation range

Species	First strip (10 years)	Second strip (10 years)	Third strip (10 years)	Block clearcut (10 years)	Control[a] (60 years)
			stems ha^{-1}		
Betula alleghaniensis	640	2734	2457	1500	167
Acer saccharum	320	1800	2058	358	543
Fagus grandifolia	160	2533	743	442	387
Prunus pensylvanica	3760	2657	971	7625	11
Acer pensylvanicum	640	1800	1143	250	62

[a] Data for control stand from Bormann et al. 1970.

pensylvanica than on strip 1 or the block clearcut (Tables 7, 10). All strips had a more desirable mix of *Betula* and *Acer* compared with the undisturbed stand on the control watershed (Table 10). However, the current mix on the strips can be expected to undergo marked changes in the ensuing years. In other 15 years, regrowth on our study sites will be reaching an age for which more is known about species composition and stand development (Leak et al. 1969; Solomon and Leak 1969), and a more thorough evaluation of strip cutting will be possible.

Betula alleghanienis occurred in maximum numbers on the block clearcut, but *Prunus pensylvanica* was the second most numerous species (Table 7) and had by far the greatest biomass. Competition from *Prunus pensylvanica* may result in a lag in productivity of commercial species on the block clearcut compared with the strip cut. Regeneration strategies for *Prunus pensylvanica* are complex (Marks 1974; Marks and Bormann 1972), but the higher density of this species in the block cutting may be partly in response to a higher initial nutrient release after block cutting. Safford and Filip (1974) reported that fertilization greatly stimulated *Prunus pensylvanica* to the detriment of other commercial species in a 4-year-old northern hardwood stand.

The regrowth on both watersheds has other important roles, such as preventing erosion and curbing nutrient losses. The low turbidities in streams coupled with visual observations throughout the watersheds show that regrowth has stabilized all soil disturbance and that erosion will not be prolonged. Several Hubbard Brook studies have shown the important role reproduction plays in recovery of nutrient cycles immediately after harvest or other disturbances (Dominski 1971; Marks and Bormann 1972; Likens et al. 1978).

The density and rapidity of regrowth also are advantageous in helping to reduce the visual impacts of cutting. With regard to the visual or esthetic impact, strip cutting may be less displeasing than other forms of clearcutting. The uncut strips can be used to shield the cut areas from view, and break the openness created by large clearcut blocks and patches (Fig. 14).

Conclusion

Commercial clearcutting of northern hardwoods, whether by progressive strips or blocks, is a severe disturbance to the forest ecosystem. However, our study indicates that if care is taken during logging, and if sawtimber rotation lengths are followed, there should not be major adverse impacts on site nutrient capital, stand regeneration, or productivity. By the 10th year after harvest, hydrologic and nutrient budgets had returned nearly to preharvest levels, and a closed canopy had formed. Compared with block clearcutting, progressive strip cutting moderates effects on hydrologic and nutrient cycles, and may result in a more desirable mix of commercial species in the new stand.

Acknowledgment

Vincent Levasseur, forest technician at the Hubbard Brook Experimental Forest, maintained instruments and installations and collected much of the basic hydrologic and climatic data used in this paper.

Figure 14.—Summer and winter views across block clearcut (foreground), strip cutting (center), and clearfelling (far right).

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Two even-age management systems, progressive strip cutting and block clearcutting, have been studied since 1970 on small watersheds at the Hubbard Brook Experimental Forest, New Hampshire. In the strip cutting, all merchantable trees were harvested in a series of three strips over 4 years (1970–74). In the block clearcutting, all trees were harvested in a single operation in 1970. This paper contrasts progressive strip cutting and block clearcutting for the 10-year period after initiation of harvest in terms of hydrologic response, erosion losses, stream water ions, nutrient leaching, nutrient removals in harvested products, and natural regeneraion of vegetation.

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Keywords: water yield; watershed; hydrology; soil nutrients; nutrient cycling; nutrient budget; stand regeneration; Hubbard Brook

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Stem-Quality Changes on Young, Mixed Upland Hardwoods After Crop-Tree Release

David L. Sonderman

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Abstract

Relative change of several types of stem defects was studied over an 8-year period to determine the effects of crop-tree thinning on the development of tree quality. Special interest was given to changes in relative quality associated with defect indicators of crop trees compared to trees in unthinned plots. The relative quality classes of the crop trees went from "poor" to "medium" for red maple and "poor" to "good" for aspen. The oaks stayed in the poor classification and yellow-poplar remained unchanged in the medium classification. Results showed a decrease in the number of epicormic branches on the crop trees, and an increase in the size of live limbs.

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Introduction

Forest managers need information on stem quality to better assess young hardwood trees. Quantifying limb-related defects is one method of evaluating how young growing stock stands should be thinned to grow the best possible defect-free stems. Little work has been done on developing the methodology for relating limb-defect changes over time to different thinning practices, particularly crop-tree release. However, one study showed that thinning young white oaks to low density levels resulted in severe epicormic branching (Dale 1968). It was found that quality losses more than offset gains from increased volume when stocking was reduced below 50 percent. In a more recent study of a young mixed-oak stand, the number of live and dead limbs increased substantially more in the heavily thinned plots than in the unthinned plots (Sonderman 1985). This confirms the common belief that stand density affects stem quality after only a few years. Additional research has shown that heavy thinning in young white oak stands has delayed, if not substantially reduced, the potential to develop high-quality stems.

In this study, various types of limb-related defects were examined on a 17-year-old mixed upland hardwood stand that had been thinned by a crop-tree release. The potential crop trees were selected on the basis of tree form, crown position, and spacing. The stands were thinned to free the crowns of the selected crop trees on all sides without leaving large gaps in the canopy. These data, combined with other hardwood quality information (Dale and Sonderman 1984; Sonderman 1984a, b; Sonderman 1985, 1986), comprise an important data base for future reference and analysis of limb-related defects.

The Stand

The 3-acre stand in this study is located on the Vinton Furnance Experimental Forest in southern Ohio. The original stand, which was clearcut in 1959, contained mature, even-aged, fully stocked, mixed-oak species on a good site. In 1977, the young stand was divided into two treatment areas—one thinned as a crop-tree release and the other left as a control. The crop-tree release contained seven 1/10-acre plots and the control eight 1/10-acre plots. A 1/2-chain-wide isolation strip was left around each treatment. All plots were about the same in density, age, site class, species, and quality. Species composition consisted of aspen, red maple, sugar maple, mixed oaks, yellow-poplar, black cherry, blackgum, butternut, beech, red elm, and hickory. From these plots, 259 study trees were selected and measured. Potential crop-tree selection was based on crown position, vigor, spacing, size, and apparent quality. Six groups were used in the analysis: oak, yellow-poplar, red maple, aspen, miscellaneous, and "all" species. Red maple was the most common species, accounting for 38 percent of the total trees in the stand.

Methods

All trees 3.6 inches or larger in diameter at breast height (d.b.h.) were graded by the quality classification system developed by Sonderman and Brisbin (1978). This system measures limb-related external defects on both the first and second 8-foot section of the butt 16-foot log on each tree. Measurements were made before thinning in 1977 and again in 1985. Limbs are branches 0.3 inch or larger in diameter. Branches smaller than 0.3 inch are classed as epicormic branches. Various stem characteristics and limb-related defects were identified and classified on each selected tree. The following tree characteristics were measured:

- d.b.h.
- total height
- crown class
- crown ratio
- sweep and crook
- number of live limbs on the first and second 8-foot section of the butt 16-foot log
- size of the largest live limb on the first and second 8-foot section of the butt 16-foot log
- number of dead limbs on the first and second 8-foot section of the butt 16-foot log
- size of the largest dead limb on the first and second 8-foot section of the butt 16-foot log
- number of epicormic branches on first and second 8-foot section of the butt 16-foot log

Epicormic branches were grouped into three categories to make counting easier: (1) trees with no epicormic branches, (2) trees with one to six epicormic branches, and (3) trees with seven or more epicormic branches.

As part of the quality classification system, a relative quality index was used to measure gross quality changes. This was done by assigning a numerical value to selected tree characteristics to be used as indexes:

Crown Class	Value
Dominant	4
Codominant	3
Intermediate	2
Suppressed	1
Sweep and Crook (Deviation in inches)	Value
1	4
2–4	3
5–6	2
7–8	1
9+	0
Fork, Rot, or Seam	0
Limb Count (Limb ≥ 0.3 inch)	Value
1–2	4
3–4	3
5–8	2
9–16	1
17+	0

By adding the individual values, the relative quality class of a tree was determined as follows:

Sum of individual values	**Relative quality class**
1–7	Poor
8–9	Medium
10–12	Good

Determining relative quality was the first step in quantifying tree characteristics that are important for growing quality trees. In-dept analyses and comparison of individual tree characteristics by species groups are included in this report. Additional information on the measurement of individual tree characteristics was published by Sonderman (1979). Computations were made using weighted averages.

Results and Discussion

Relative Quality Index

The relative indexes (Fig. 1) showed that aspen increased most in quality in the crop-tree release, going from the "poor" to "good" classification. However, in the control, aspen stayed in the "poor" quality class. Yellow-poplar's performance showed the least change, remaining as a "medium"-quality tree in both treatments. Figure 1 shows that crop-tree thinning had a positive effect on red maple and aspen, but little effect on yellow-poplar or oak.

Diameter and Height Growth

Crop-tree release had a greater effect on diameter growth than the control. Table 1 shows an overall increase in average tree diameter of 2.6 inches for "all" species combined in the crop-tree plots versus only 1.4 inches in the control plots for the 8-year period. Yellow-poplar in the crop-tree release was the fastest growing, increasing 4.3 inches in diameter from 1977 to 1985. The oak group had the slowest diameter growth of all the species.

Height growth (Table 1) was best for yellow-poplar in the crop-tree treatment, but second to aspen in the control plots. Height growth for the oak group, as with diameter, was slowest of all the species measured. There were virtually no differences between the oak trees in the control plots and those in the crop-tree release plots. Comparing the data for "all" species, the crop-tree treatment outgrew the control in height by 2.7 feet.

Crown Ratio

Crown ratio is the ratio of live crown length to total tree height (Table 1). Thinning around a tree in a crop-tree release provides additional light, which can cause an increase in limb growth. This results in a downward extension of the crown and an increase in crown ratio. This was true in the crop-tree treatment which increased by 1.2 percent when analysed by "all" species. When individual species were analyzed, the crown ratios for aspen and yellow-poplar increased by about 15 percent in the crop-tree plots, but only by about 2 percent in the control plots. Similar crown-ratio results were found in relation to thinning in an earlier study by Sonderman (1984b).

Limb Defects per Square Foot of Surface Area

As a tree grows, the surface expands, causing an increase in surface area. If there are no changes in the number of defects on the surface, then the number of defects per square foot of surface area will decrease. Changes in limb defects per square foot of surface area are shown in Table 1. There was an overall reduction in the number of defects per square foot of surface area between 1977 and 1985 in both the crop-tree treatment and control on the butt 16-foot log of the study trees. Neither the crop-tree treatment nor the control appeared to vary much when analyzed for "all" species, but because the crop trees had greater diameter growth than the control trees, they had more surface area and developed more limb-related defects.

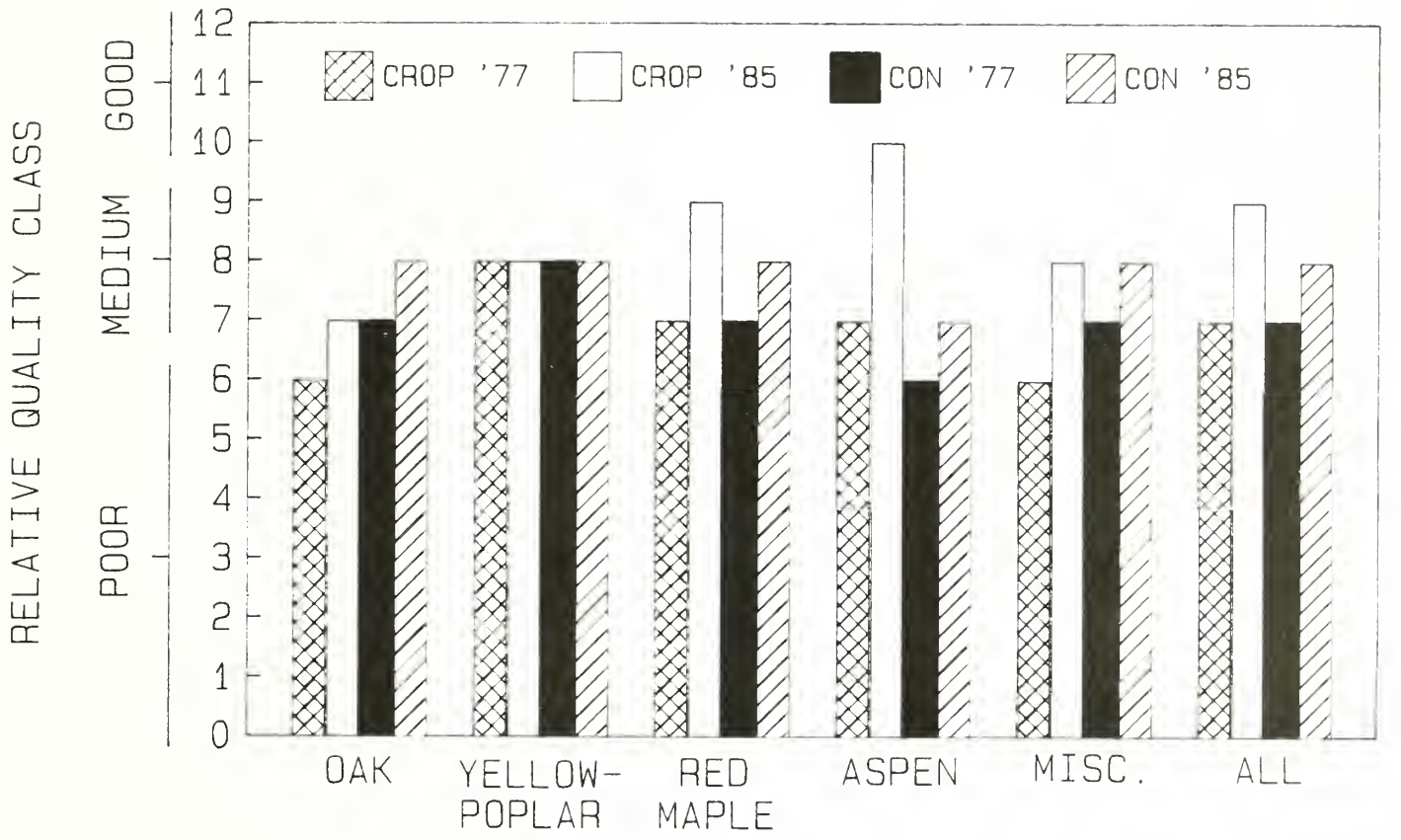

Figure 1.—Average relative quality index by species and treatment, 1977–85.

Live Limbs

Generally, there were more live limbs (Table 2) on the second 8-foot section of the butt log of the tree than on the first. There also was a reduction in the number of live limbs on the second 8-foot section for both the crop-tree release and control from 1977 to 1985. However, on the second 8-foot section in 1985, oak showed an increase in live limb frequency for both the crop-tree and control treatments. By contrast, the number of live limbs on red maple decreased dramatically for both treatments. Red maple live limbs stayed on the tree longer and reached a size of 3 to 4 inches in diameter before dying. Few new live limbs developed during that time. The result was a decrease in the number of live limbs and an increase in the size of dead limbs (Table 3).

Dead Limbs

The average number of dead limbs for "all" trees (Table 2) was reduced substantially from 1977 to 1985, but the difference between treatments was small. The full stocking of the control plots caused some natural pruning, resulting in fewer but larger dead limbs remaining on the stems over the 8-year growth period. Size was the reason for dead limbs hanging on, because large limbs usually do not prune off easily or quickly. The average diameter (Table 3) of the dead limbs in the secnd 8-foot section for "all" species in 1985 was 2.92 inches for the crop-tree treatment and 3.03 inches for the control.

Table 1.—Summary of average tree characteristics in 1977 and 1985, by species group and treatment

Species group	Crop-tree release		Control	
	1977	1985	1977	1985
	D.B.H. (inches)			
Oaks	5.1	6.5	4.8	5.6
Yellow-poplar	5.1	9.4	4.9	7.6
Red maple	5.3	8.1	5.4	6.8
Aspen	5.0	7.8	4.3	6.8
Miscellaneous[a]	5.4	7.4	4.9	6.0
All	5.3	7.9	5.1	6.5
	HEIGHT (feet)			
Oaks	44.0	46.2	43.0	46.3
Yellow-poplar	47.5	63.8	47.9	60.7
Red maple	47.6	59.3	46.5	54.3
Aspen	51.0	64.5	49.2	71.1
Miscellaneous[a]	44.1	52.4	44.8	50.5
All	46.2	56.8	46.0	53.9
	CROWN RATIO (percent)			
Oaks	35.0	26.0	30.0	22.1
Yellow-poplar	26.8	41.4	25.7	28.1
Red maple	49.1	48.2	38.3	35.6
Aspen	30.0	45.0	26.4	28.6
Miscellaneous[a]	37.8	37.6	27.5	25.4
All	41.0	42.2	31.4	29.4
	DEFECTS/FT^2 SURFACE AREA[b] (number)			
Oaks	0.270	0.165	0.452	0.191
Yellow-poplar	.100	.116	.147	.060
Red maple	.387	.070	.396	.092
Aspen	.812	.179	.836	.608
Miscellaneous[a]	.447	.130	.411	.107
All	.373	.104	.383	.120

[a]Includes sugar maple, black cherry, blackgum, hickory, butternut, beech, and red elm.

[b]Live and dead limbs, butt 16-foot section.

Table 2.—Average number of live and dead limbs in butt and second 8-foot sections, 1977–85, by species group

Species group	Crop-tree release				Control			
	1977		1985		1977		1985	
	Live	Dead	Live	Dead	Live	Dead	Live	Dead
	BUTT 8-FOOT SECTION							
Oaks	—	1.70	2.23	0.39	—	4.08	1.03	1.17
Yellow-poplar	—	0.55	—	1.82	—	1.02	—	0.33
Red maple	0.04	2.43	0.03	.29	0.19	2.65	0.22	.39
Aspen	—	7.17	—	—	—	6.57	—	6.64
Miscellaneous[a]	—	2.91	—	1.55	.09	2.39	.32	.78
All	.04	2.40	.17	.94	.09	2.57	.28	.84
	SECOND 8-FOOT SECTION							
Oaks	—	8.96	3.57	1.68	0.93	11.61	1.83	4.00
Yellow-poplar	0.74	2.74	0.20	6.34	.63	3.90	1.67	1.61
Red maple	3.44	9.95	1.41	2.74	3.21	10.33	0.85	3.43
Aspen	—	23.73	—	11.27	1.28	19.98	—	25.25
Miscellaneous[a]	.54	15.38	1.08	4.73	1.06	12.21	.76	2.99
All	1.76	11.17	1.28	4.03	1.71	10.57	.98	3.89

[a]Includes sugar maple, black cherry, blackgum, hickory, butternut, beech, and red elm.

Table 3.—Average diameter, in inches, of largest live and dead limbs in butt and second 8-foot sections, 1977–85, by species group

Species group	Crop-tree release				Control			
	1977		1985		1977		1985	
	Live	Dead	Live	Dead	Live	Dead	Live	Dead
	BUTT 8-FOOT SECTION							
Oaks	—	0.83	0.50	2.50	—	0.55	1.50	2.90
Yellow-poplar	—	.50	—	1.35	—	1.03	—	2.25
Red maple	1.50	.67	2.00	1.55	0.95	.62	1.75	1.84
Aspen	—	.50	—	—	—	.50	—	1.37
Miscellaneous[a]	—	.54	—	1.80	1.00	.59	0.83	2.18
All	1.50	.61	1.25	1.62	.96	.62	1.28	2.06
	SECOND 8-FOOT SECTION							
Oaks	—	0.62	1.00	5.41	0.91	0.82	1.50	3.00
Yellow-poplar	1.00	.56	5.00	2.20	.75	.64	1.70	1.35
Red maple	1.01	.74	4.00	3.27	.98	.75	3.68	3.45
Aspen	—	.50	—	2.00	.75	.53	—	2.53
Miscellaneous[a]	1.20	.87	3.41	2.46	1.25	.69	1.47	2.99
All	1.04	.77	3.71	2.92	1.00	.71	2.41	3.03

[a]Includes sugar maple, black cherry, blackgum, hickory, butternut, beech, and red elm.

Yellow-poplar was the only species to increase in the number of dead limbs in both 8-foot sections of the crop-tree treatment, while aspen was the only species to increase in the number of dead limbs in both 8-foot sections of the control. The oak group had the largest dead limbs, averaging 5.4 inches in diameter in the second 8-foot section of the crop-tree treatment. Aspen and yellow-poplar had the smallest dead limbs in that same 8-foot section.

Epicormic Branches

Study results show that the percentage of epicormic branches increased the most in the control plots (Table 4). An increase in light around the crop trees caused the existing limbs on the stem to continue to grow larger. This resulted in little new epicormic branch activity. Natural variation in sprouting ability among species also was a factor. When the data were analyzed by individual species, red maple and oak were the most prolific sprouters, while yellow-poplar and aspen barely sprouted. Smith (1977) found similar effects on 60-year-old yellow-poplars following thinning. Another study (Brinkman 1955) showed that dominant and codominant trees had a tendency to "feather out" less with epicormic branches than intermediate or suppressed trees. Since this way a crop-tree release that favors dominant and codominant trees in the residual stand, one would anticipate less epicormic branching. Although some epicormic branching may be species related, a large amount of branching was influenced by the degree of thinning and the residual stocking of the stand.

Table 4.—Percentage of trees with epicormic branches, 1977–85, by species group

Species group	Crop-tree release		Control	
	1977	1985	1977	1985
	BUTT 8-FOOT SECTION			
Oaks	0.0	40.0	7.1	71.9
Yellow-poplar	0.0	0.0	0.0	3.7
Red maple	5.8	38.0	0.0	45.2
Aspen	0.0	0.0	0.0	0.0
Miscellaneous[a]	3.7	7.4	0.0	26.0
All	3.7	22.5	0.5	32.3
	SECOND 8-FOOT SECTION			
Oaks	0.0	40.0	7.1	85.6
Yellow-poplar	0.0	18.1	7.4	18.5
Red maple	11.6	44.0	3.0	49.9
Aspen	0.0	0.0	0.0	0.0
Miscellaneous[a]	3.7	7.4	0.0	39.9
All	6.2	32.3	2.7	42.4

[a]Includes sugar maple, black cherry, blackgum, hickory, butternut, beech, and red elm.

Results of a previous study showed that heavily thinned stands with low residual stocking and open canopys resulted in heavy epicormic sprouting (Dale and Sonderman 1984).

Summary and Conclusion

Tree quality is not markedly affected by residual stand-density levels that are maintained above C-level stocking. The crop-tree release in this study resulted in many changes in stem-quality and growth characteristics. The average diameters (d.b.h.), heights, and crown ratios increased in the crop-tree treatment, as did the number of limb defects per square foot of surface area. This study showed an increase in live and dead limbs in the crop trees, and a decrease in epicormic branches. The additional live and dead limbs occurred because the expanded growing space around each tree that resulted from thinning allowed existing live limbs to develop (grow) and curtailed natural pruning of the dead limbs. For this reason, fewer epicormic branches formed.

In some instances, opening the canopy around crop trees may be a greater stimulus to the growth of already established branches than to the formation of new epicormics. Fewer epicormics would, over time, mean a reduction in the number of new stem defects on the prime grading section (butt 16-foot log) and result in improved tree quality in the future. The fact that dominant trees, which were left for the final crop trees, were known to sprout less than codominants and intermediates may have contributed to fewer epicormic branches. All of this information will help evaluate the quality of young growing-stock trees and serve as a basis for selecting silvicultural treatments. Other important findings were:

- Epicormic branches increased most on the second 8-foot section of the butt 16-foot log.
- The oaks had the most epicormic branches of all the species.
- The number and size of the live and dead limbs were greatest on the second 8-foot section of the butt 16-foot log.
- The oak species in the crop-tree release plots had the largest number of live limbs in both the first and second 8-foot sections of the butt 16-foot log. They averaged more than 3.5 limbs per tree in the second 8-foot section.
- Yellow-poplar was the only species to increase in the number of dead limbs in the crop-tree release plots during the 8-year growth period.

- The oak trees in the crop-tree release plots had the largest dead limbs. The average number of these large dead limbs was fewer than 2 per tree.

Because this study was limited to a crop-tree thinning, a single site class, and one age group, caution should be used when applying these data to other trees and stands.

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Keywords: Stand density; thinning; stem quality

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**Northeastern Forest
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NE-RP-598

Effects of Herbicide Release on the Growth of 8- to 12-Year-Old Hardwood Crop Trees

G. W. Wendel
Neil I. Lamson

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Abstract

In 8- to 12-year-old Appalachian hardwood stands, crop trees were released by stem injecting competing trees with a 20 percent aqueous solution of glyphosate. Species released were black cherry, red oak, and sugar maple. Release treatments were (a) injection of all trees within a 5-foot radius of the crop tree bole and (b) injection of all trees whose crown touched the crop tree. Five-year diameter growth of all species was significantly increased by both release treatments, but height growth was not affected by either treatment. Survival of released crop trees was higher and crown-class retrogression of released trees was less than unreleased trees. Glyphosate was effective in controlling most hardwood species during the 5 years of observation.

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Introduction

Some control of species composition in young hardwood stands can be accomplished by releasing trees of desirable species and form (Erdmann 1983). Theoretically, released trees should grow faster and have a greater chance of attaining and maintaining dominance in the new stand. Major obstacles in regulating species composition in naturally regenerated stands are the variety of species, stem quality, large number of stems, and growth differences among species.

Early work by Trimble (1973, 1974) generally showed that 7-year-old stems of yellow-poplar, *Liriodendron tulipifera* L.; black cherry, *Prunus serotina* Ehrh.; and northern red oak, *Quercus rubra* L., did not respond in diameter or height growth when all competing trees within a 5-foot radius of the bole were cut. In a 9-year-old stand, Lamson and Smith (1978) measured response of released sugar maple, *Acer saccharum* Marsh.; red oak; black cherry; and yellow-poplar crop trees. All trees were cut that were one-half or more as tall as the crop tree and were within a radius of 5 feet of the crop tree. Their general conclusions were (1) that release did not significantly improve height or diameter growth or length of clear stem, and (2) that a large portion exhibited crown-class regression in the 5-year period after release. One factor affecting response of crop trees in these studies, particularly in the 7-year-old stands, was the vigorous sprouting from the cut stems surrounding the crop tree.

In this study, we injected glyphosate, a herbicide, into the base of competing stems and measured crop-tree response in d.b.h. growth, height growth, and changes in crown class. Glyphosate injection is very effective in eliminating or reducing sprouting of most hardwood species (Wendel and Kochenderfer 1982).

The Study

Seedling-origin crop trees in three 8- to 12-year-old naturally and artificially regenerated hardwood stands were selected for release. Species included codominant and intermediate black cherry; codominant, intermediate, and suppressed red oak; and intermediate sugar maple (Table 1). Competing trees were injected with a 20 percent aqueous solution of glyphosate. Injections were spaced at intervals of 1.5 inches edge-to-edge around the base of all stems that had a basal diameter larger than 1.0 inch. Approximately 1.5 ml of solution was injected into each incision. In the 8- and 10-year-old stands, competing trees within a radius of 5 feet of the crop tree bole were injected. In the 12-year-old stand, competing trees whose crowns were touching under or over the crop-tree crown were injected (Table 1). All crop trees were permanently marked. Crop trees were randomly selected, and every other crop tree was released.

D.b.h., total height and crown class of each crop tree were recorded at the time of and 5 years after treatment. Analysis of variance was used to test for differences in d.b.h. and height growth.

Results

Survival

Except for codominant black cherry and intermediate sugar maple, survival was better for released trees than it was for control trees (Table 2).

Table 1.—Species, number of trees, and type of release used in the study

Species	Initial stand age[a]	Origin[b]	Initial crown class[c]	Number of trees		Type of release
				Control	Released	
Black cherry	8	N	2	25	25	5′ radius around bole
Black cherry	8	N	3	22	22	"
Red oak	10	P	2	35	46	"
Red oak	10	P	3	29	29	"
Red oak	10	P	4	22	14	"
Sugar maple	12	N	3	12	13	Crown touching

[a]Planted seedlings were 1-0 bare-rooted stock.
[b]N = natural, P = planted.
[c]2 = codominant, 3 = intermediate, 4 = overtopped.

Table 2.—Five-year height growth and survival of control and released trees

Species	Initial age	Initial crown class[a]	Survival		Initial height		Height-growth of survivors		
			Control	Released	Control	Released	Control	Released	Significance[b]
			---Percent---		*----------Feet----------*				
Black cherry	8	2	100	92	16.6	16.6	10.8	10.7	NS
Black cherry	8	3	87	100	14.1	14.3	7.6	7.7	NS
Red oak	10	2	80	98	14.4	14.8	8.8	8.7	NS
Red oak	10	3	65	86	13.0	12.3	5.0	6.5	NS
Red oak	10	4	9	57	10.1	10.9	2.9	3.0	NS
Sugar maple	12	3	100	100	22.7	24.3	6.5	7.0	NS

[a]2 = codominant, 3 = intermediate, 4 = overtopped.
[b]NS = not significantly different. Analysis of variance.

Height growth

For all species and crown classes, 5-year average height growth did not differ significantly between control and release trees (Table 2).

D.b.h. Growth

Five-year average d.b.h. growth was significantly greater for all released trees except 10-year-old overtopped red oak (Table 3). However, in all instances 5-year d.b.h. growth was nominally greater for released trees than control trees. Regardless of crown class, the difference in 5-year d.b.h. growth between control and released trees averaged 0.4 inch for black cherry, 0.3 inch for red oak, and 0.7 inch for sugar maple. Also, the 5-year d.b.h. growth for released 12-year-old intermediate sugar maples was similar to the response for codominant 8-year-old black cherry trees.

Crown-class Changes

A higher percentage of released than control trees remained the same or improved in crown class during the 5 years (Table 4). A large proportion of black cherry in the codominant crown class in both control and released treatments retained their original crown class during the 5 years. However, of the intermediate black cherry, 57 percent of the control trees retrogressed to the overtopped crown class or died. Twenty-four percent of the released intermediates became codominants compared to only 4 percent for the controls.

A higher percentage of released than control red oaks retained their original crown class, regardless of crown class. In contrast, there was higher mortality and retrogression to lower crown classes among the control red oak.

For sugar maples that were initially intermediate, 69 percent of the released trees were codominant 5 years after treatment, while none of the control trees moved into the codominant class.

Discussion and Conclusions

The results of this study have shown that tree injection with a 20 percent solution of glyphosate is an effective way to eliminate competition around selected crop trees. Earlier work by Wendel and Kochenderfer (1982) showed that most of the common Appalachian hardwoods were killed and did not resprout after 2 years following injection with glyphosate. After 5 years in this study, the effects of release are still evident.

In previous early release studies in West Virginia where a 5-foot release radius was used, 7- and 9-year-old black cherry and red oak crop trees did not respond in height or diameter growth (Smith 1977). Vigorous sprouts from the cut stems were suggested as a possible reason for the poor response on the crop trees. In our study, using the same release criteria, we found that treated 8-year-old black cherry and 10-year-old red oak responded in d.b.h. growth and had less crown-class retrogression when a herbicide was used to kill competitors. The herbicide application reduced sprouting by killing the competing trees, thus leaving the crop trees competition-free for a longer period of time.

Smith (1977) also noted that crop trees in young stands were often severely damaged by grapevines that flourished following release.

Table 3.—Five-year d.b.h. growth of control and released crop trees

Species	Initial age	Initial crown class[a]	Initial d.b.h.		D.b.h. growth of survivors	
			Control	Released	Control	Released[b]
			Inches			
Black cherry	8	2	1.5	1.6	1.2	1.6**
Black cherry	8	3	0.9	0.8	0.6	1.0*
Red oak	10	2	1.1	1.2	0.8	1.1*
Red oak	10	3	0.8	0.8	0.3	0.6*
Red oak	10	4	0.8	0.6	0.2	0.4NS
Sugar maple	12	3	1.9	1.9	0.7	1.4**

[a]2 = codominant, 3 = intermediate, 4 = overtopped.
[b]NS = not significantly different; * = P<0.05; ** = P<0.01; analysis of variance.

Table 4.—Distribution of control and released trees by crown class, at the end of five growing seasons

Species	Initial age	Initial crown class[a]	Crown class remained same or improved		Dead	
			Control	Released	Control	Released
			Percent			
Black cherry	8	2	68	88	0	8
Black cherry	8	3	43	76	13	0
Red oak	10	2	14	22	20	2
Red oak	10	3	3	48	62	14
Red oak	10	4	9	50	91	43
Sugar maple	12	3	42	100	0	0

[a]2 = codominant, 3 = intermediate, 4 = overtopped

Since codominant 8-year-old black cherry and 10-year-old red oak responded to release, we would recommend releasing these. The results of this study also showed that some of the intermediate black cherry, sugar maple, and red oak responded significantly in diameter growth to release. However, 5 years after release only 3 percent of intermediate red oak and 24 percent of intermediate black cherry were codominant stems. How many of these codominant trees will retain this position until final harvest is not known. We would recommend releasing some intermediate black cherry where there is a need to improve species composition. We would not recommend releasing 10-year-old intermediate red oak trees. Also, we would recommend releasing 12-year-old intermediate sugar maple.

A major advantage of tree injection with glyphosate is that sprouting of most hardwood species is reduced, thereby providing a longer release period for the crop tree. Injection is also a safe and clean method of applying herbicides and environmental effects are minimized because the herbicide is applied directly to the target species. Cutting of competing trees on the other hand may provide immediate release, but sprouting may be a problem later on. For release of stump sprout crop trees, however, cutting may be the only method that can be used. Also, because cut trees are readily visible it may be easier to achieve a desired degree of release by cutting.

Miller (1984) showed that in 12-year-old stands, chain saw release cost 42 cents per crop tree, injection with a 20

percent glyphosate solution cost 61 cents per crop tree, and basal spraying with a 4 percent mixture of 2, 4–D and fuel oil cost 80 cents per crop tree. However, Miller's study did not evaluate the long-term effectiveness of the three release methods. In younger hardwood stands, where slower growing, desired species may not survive without early release, injection of competing stems with herbicide might be an effective method for maintaining and increasing growth of selected crop trees. Failure to release certain species early may negate future release growth response.

Our study demonstrated that glyphosate will control many hardwood species but that the longer term cost/effectiveness compared to other methods has not been determined. If species composition is not a concern, we suggest a cutting release when trees are more than 25 feet tall (Smith 1977). Unless circumstances dictate otherwise, crop trees of desired species are best picked from the pool of dominant and codominant trees.

For those who might be interested in using glyphosate to release crop trees, we recommend the following:

- Use a 20 percent aqueous solution of glyphosate.
- Inject about 1.5 ml of solution per incision, space incisions at about 1.5 inches edge-to-edge. One incision is sufficient for a 1.0-inch d.b.h. tree.
- Inject trees when they are dormant or approaching dormancy, but before sap begins to flow in the spring. When the sap is flowing, much of the herbicide solution can be forced out of the incision.
- To eliminate a sprout clump, make injections in the stump close to the ground. Thus, treatment of individual sprouts can usually be avoided. Do not release sprout origin crop trees by injecting competing sprouts on the same stump.

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Caution

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers—out of reach of children and pets—and away from foodstuff.

Apply pesticides selectively and carefully. Do not apply a pesticide when there is a danger of drift to other areas. Avoid prolonged inhalation of a pesticide spray or dust. When applying a pesticide, it is advisable that you be fully clothed.

After handling a pesticide, do not eat, drink, or smoke until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first-aid treatment given on the label, and get prompt medical attention. If the pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Dispose of empty pesticide containers by wrapping them in several layers of newspaper and placing them in your trash can.

It is difficult to remove all traces of a herbicide (weed killer) from equipment. Therefore, to prevent injury to desirable plants do not use the same equipment for insecticides and fungicides that you use for a herbicide.

NOTE: Registrations of pesticides are under constant review by the U.S. Department of Agriculture. Use only pesticides that bear the USDA registration number and carry directions for home and garden use.

Wendel, G. W.; Lamson, Neil I. 1987. **Effects of herbicide release on the growth of 8- to 12-year-old hardwood trees.** NE-RP-598. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 4 p.

In 8- to 12-year-old Appalachian hardwood stands, crop trees were released by stem injecting competing trees with a 20 percent aqueous solution of glyphosate. Species released were black cherry, red oak, and sugar maple. Release treatments were (a) injection of all trees within a 5-foot radius of the crop tree bole and (b) injections of all trees whose crown touched the crop tree. Five-year diameter growth of all species was significantly increased by both release treatments, but height growth was not affected by either treatment. Survival of released crop trees was higher and crown-class retrogression of released trees was less than unreleased trees. Glyphosate was effective in controlling most hardwood species during the 5 years of observation.

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Keywords: Appalachian hardwoods, crop trees, release, herbicide

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NE-RP-599

Supply and Demand of Timber for Wood Turning in Maine

Eric H. Wharton
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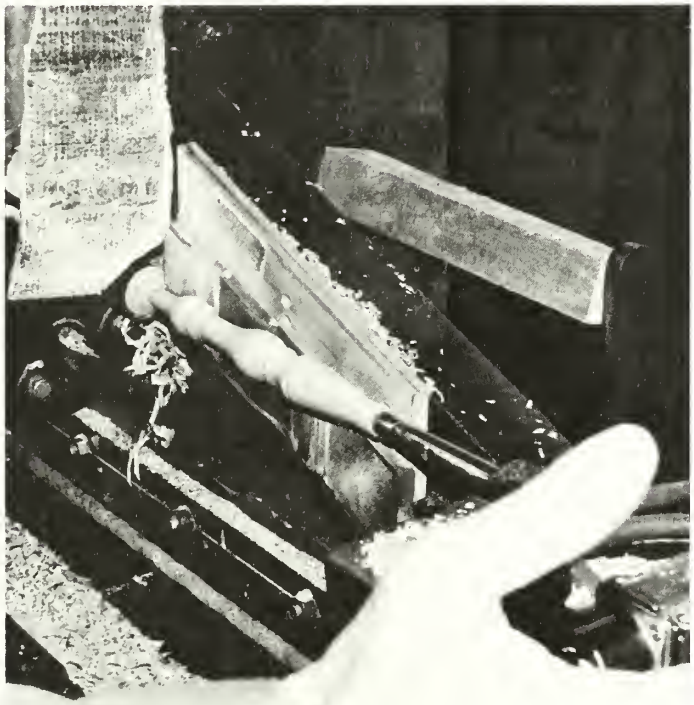

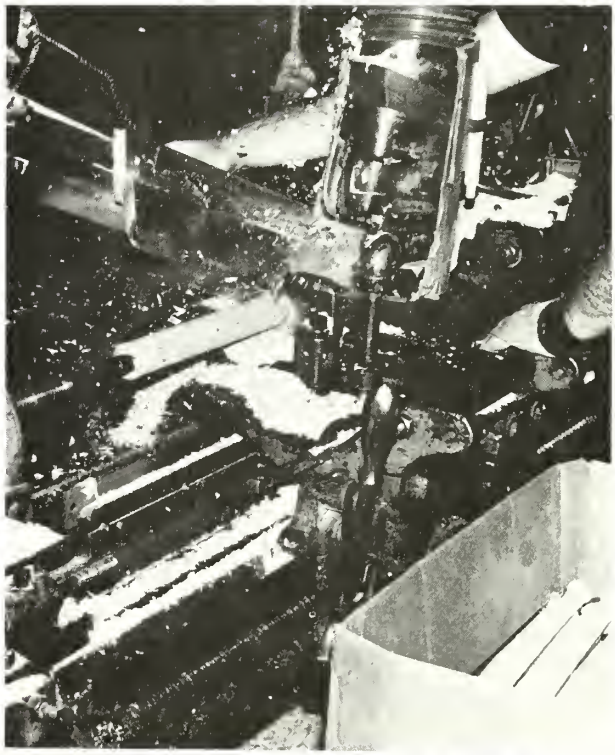

Abstract

Manufacturers of wood-turned products in Maine primarily use sugar maple, yellow birch, and paper birch. Other abundant and suitable species such as aspen and red maple grow in Maine, but are used to a limited extent by the state's turnery mills. The resource supply of the primary species used by turnery mills has increased since the last inventory, but the increase has been primarily in the small diameter classes, resulting in a decline of high-quality timber. The growth to removals ratios of sugar maple and yellow birch are much smaller than the ratio for paper birch. Paper birch is growing twice as fast as it is being removed for industrial forest products.

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Background

Clothespins, dowels, and candlesticks: products so common, seldom are they given a second thought. Where do they come from? Who makes them? Many are manufactured by a wood-turning industry in Maine.

For the purpose of this report, wood turning is a process that converts harvested logs or bolts into a wood product by lathing, or a product that will eventually be lathed. All wood-turned products may be used as manufactured, or converted into a secondary product. Most of the wood-turning mills in Maine manufacture wood squares, dimension stock usually 50 inches long, varying in length from 1/2-inch to 4 1/2-inch square size.

From the dried wood squares, wood products are manufactured that range from plain dowels to ornate objects. Dowels can range in size from as small as 3/16-inch, used for cotton-tipped swabs, to as large as 3 inches, used for handrails. The final wood-turned product is shaped either manually or on an automatic lathe, using either clear precut sections of the square or the entire square.

Not all wood-turning mills in Maine produce squares as their sole manufactured product. Some mills produce squares as an additional product. Manufacturers of trapstock, for example, primarily produce material for lobster traps, but they also manufacture squares. If a mill saws only squares and sells them to someone else, it is usually classified as a square or bar mill. For convenience, any mill that has produced squares, or similar dimension stock, that will be turned either on-site or at some other establishment has been classified as a wood-turning mill in this report.

Many of the items manufactured by the wood-turning industry in Maine are components of goods later manufactured for general consumption. Dowels, chair rungs, glue pins, and plugs are manufactured for the furniture industry; handles are manufacured for tools and knives; and rings, balls, and beads are manufactured for many different types of secondary manufacturing. Products such as drumsticks, gavels, bowling pins, candlesticks, and novelty items that are manufactured for direct consumption comprise a very small portion of the wood-turning industry in Maine.

To manufacture wood-turned products, timber harvesters supply raw material to the wood-turning mills in the form of turnstock. Commonly referred to as turnery bolts, these are short log sections nominally 4 feet long—usually 50 inches—from which blanks are sawn and turned. Turnstock must meet stringent quality specifications, including specific size and form requirements.

Mills have traditionally used 50-inch lengths for turnstock, but these bolts are in short supply. High insurance rates, especially from workers' compensation, have forced many timber harvesters to mechanize, resulting in more tree-length harvesting. Boltwood is available, but lacking the price differential to extract usable wood from pulpwood piles, much of the material suitable for turnstock is sent to pulpmills. As a result, mills that manufacture wood-turned products have begun to accept multiples of 50-inch bolts: 8-foot, 12-foot, even up to 24-foot lengths, not including trim allowance.

Long-log sections also may be in short supply, according to recent trends. Statistics provided by Powell and Dickson (1984) show that supplies of high-quality timber that can be used for longer lengths are declining. Sawtimber volume has increased in Maine between 1971 and 1982, largely through increases in construction log-grade timber. The portion of all other grades, including high-quality timber, decreased by 5 percent.

How much timber is available for turnstock given: (1) the species, quality, size and form specifications required by manufacturers of wood-turned products, (2) the unavailability of short-log sections resulting from more tree-length harvesting, and (3) declining supplies of high-quality sawtimber? We will report on the volume of wood used by the wood-turning industry in Maine, and the current volume on timberlands that may be suitable for turnstock. We will also discuss how this industry has changed over time, and what its future may be.

The Forest Inventory and Analysis Unit conducts two pertinent surveys.[1] One is a forest resource survey on private and public forest land, and the other is an industry canvass of all operating mills in the state. We used specific data from these two surveys to analyze the volume of wood suitable for wood-turning and the demand for turnstock by wood turning mills in Maine.

Volume of Wood Used by the Wood-turning Industry

Timber harvesters in Maine supply a variety of roundwood products to wood manufacturers. Logs and bolts are roundwood, produced by harvesting trees for industrial or consumer use. The industry canvass for 1981 showed that

[1]For a complete description of the methods used, and definitions of terms used in USDA Forest Service surveys, refer to the appendix.

438.7 million cubic feet (5.2 million cords)[2] of roundwood were harvested from Maine timberlands for all industrial forest products (Nevel et al. 1985), including pulpwood harvested to supply the 16 pulpmills in Maine. Only 6.9 million cubic feet (81.2 thousand cords) were harvested for turnstock, less than 2 percent of the total timber harvest (Table 1). A small industry, wood turning uses little of the total timber available for forest products.

During 1981, 41 mills in Maine manufactured turnstock into some form of wood-turned product. With few establishments, the wood turning industry in Maine has achieved a certain degree of stability. Maufacturers of wood-turned products consumed 7.1 million cubic feet (83.8 thousand cords) of wood in 1958, increasing their consumption to 7.6 million cubic feet (89.0 thousand cords) in 1971 (Ferguson and Kingsley 1972). In the last decade, manufacturers in Maine have increased their consumption of wood for turned products only slightly—to 8.0 million cubic feet (94.3 thousand cords) in 1981 (Nevel et al. 1985).

Despite its size, the wood-turning industry is important to Maine. It is labor intensive, often the largest employer in small towns, and manufactures high value-added products. Also, manufacturers of wood-turned products consume large proportions of a few valuable species. A variety of species are suitable for turnstock, but only a few are preferred. The most preferred are sugar maple,[3] yellow birch, and paper birch. Combined, these species comprise almost 82 percent of the timber consumed in Maine for wood-turned products.

Paper birch is most preferred by the wood-turning industry in Maine. During 1981, timber harvesters supplied 3.1 million cubic feet (36.3 thousand cords) of paper birch turnstock to manufacturers, who imported an additional 278.1 thousand cubic feet (3.3 thousand cords) from outside the state. Altogether, 3.4 million cubic feet (39.6 thousand cords) of paper birch turnstock were consumed, 42 percent of the total consumption.

Next to paper birch, yellow birch is the most important species to the wood-turning industry in Maine. Demand for yellow birch is high, but much of it is imported from outside the state. Nearly 1.8 million cubic feet (20.8 thousand cords) of yellow birch were consumed in Maine during 1981, but only 1.1 million cubic feet (13.3 thousand cords) were harvested from Maine timberlands; approximately 36 percent was imported from other states, or from Canada. Manufacturers are finding that they must rely increasingly more on sources of yellow birch outside of the state.

Yellow birch is the only species imported to any extent by the wood-turning industry in Maine. This occurs because a majority of the State's wood-turning mills are close to timberlands in New Hampshire and Vermont. In many respects the necessity to import raw material characterizes the problems facing maufacturers of specialty products in Maine. High-quality logs or bolts are usually required for processing specialty products. Short logs and bolts are available, but extracting them at tree-length harvesting operations is expensive. With declining supplies of quality logs 12 feet and longer, hauling distances have been stretched to find adequate supplies.

The next three most important species—Beech, white ash, and aspen—in 1981 accounted for a little more than 1.0 million cubic feet (12.3 thousand cords), only 15 percent of the total timber harvested for turnstock. These three species are accepted to a certain extent, but not preferred. White ash and beech are strong, moderately heavy woods with properties acceptable for turning, but supplies of quality wood are limited in Maine. Also, beech shrinks easily, rendering it difficult to kiln dry (U.S. Forest Products Laboratory 1974); manufacturers prefer species that dry easily. Aspen, found in large volumes throughout Maine timberlands, also may be unacceptable because the wood is too soft to allow it to turn well[4] without special attention to kiln drying and slicing procedures such as knife pitch and sharpness. It is primarily used to manufacture spools for wreath wire and some inexpensive tool handles.

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[2]Volumes of roundwood used for industrial products are commonly expressed as board feet or cords in Forest Service publications. However, growing-stock volume used to quantify the timber supply is usually expressed in cubic feet. In this report, cubic feet is used as the common unit of measure; the quantity of turnstock produced and consumed in Maine is expressed as cubic feet along with the equivalent volume in cords (based on 85 cubic feet of solid wood per cord). A cubic foot of roundwood used for turnstock is roughly equivalent to 5.88 board feet (International 1/4-inch rule), 0.0118 standard cord (based on 85 cubic feet of solid wood per cord), or 0.0078 standard cord (based on 128 cubic feet of wood, bark, and air space per cord).

[3]In Maine, sugar maple (*Acer saccharum*) is also called hard maple, rock maple, and sometimes white maple. The soft maples include red maple (*A. rubrum*), silver maple (*A. saccharinum*), and mountain maple (*A. spicatum*). The soft maples group should not be confused with the single species soft maple, which in Maine is also called red maple, swamp maple, and sometimes white maple. Red maple is called white maple only in areas where sugar maple is *not* called white maple.

[4]Personal communication with Albert J. Bibeau, Executive Director, Wood Products Manufacturers Association, Gardner, Massachusetts.

Table 1.—Volume of turnstock[a] consumed, by species and final disposition of the roundwood, Maine, 1981

Species	Cut and retained within state[b]	Imported from other states or provinces	Total consumption
	Thousand cubic feet		
White pine	15.5	.0	15.5
Cedar	2.6	.0	2.6
Total softwoods	18.1	.0	18.1
Soft maples	141.4	34.0	175.4
Hard maples	1,325.8	86.9	1,412.7
Yellow birch	1,130.7	634.8	1,765.5
Paper birch	3,086.7	278.1	3,364.8
Beech	279.0	70.7	349.7
White ash	225.1	8.5	233.6
Aspen	537.9	.0	537.9
Red oak	90.3	.0	90.3
Other hardwoods[c]	64.8	.0	64.8
Total hardwoods	6,881.7	1,113.0	7,994.7
All species	6,899.8	1,113.0	8,012.8

[a]Includes bolts used to manufacture lathed products through a wood turning process, and squares that will eventually be turned.

[b]Lacking markets in other states and in Canada, timber harvesters in Maine export no turnery logs or bolts.

[c]Includes basswood, yellow-poplar, and other minor species.

Of the soft maples, only red maple is currently used for wood-turned products in Maine; maufacturers produce billy clubs, fishing pole butts, and chair parts from red maple. The species is suitable for wood turning, yet its wood properties preclude it from being a preferred species. The wood of red maple turns well, but its light to heavy, reddish-brown coloring in both the heartwood and sapwood tend to make it less than a preferred species. Only 175.4 thousand cubic feet (2.1 thousand cords) of soft maples were consumed by the wood turning industry in Maine during 1981.

Location of Wood-turning Mills

The demand of all species for turnstock is greatest in western Maine. We found that nearly 48 percent of the mills were located in two counties: Franklin and Oxford (Fig. 1). Another 15 percent were located in the southern portion of adjacent Somerset County. Manufacturers of wood-turned products are concentrated in this region partially due to their proximity to population centers.

Wood-turned products fall primarily into one of two categories: products manufactured for direct consumption by the general public, or commodity products that are later remanufactured or included in products for consumption by the general public. In either case, manufacturing should be ideally located near population centers. Franklin, Oxford, and Somerset Counties are directly linked to the heaviest population and shipping centers in Maine through extensive highway systems.

Figure 1.—Location of wood-turning mills in Maine, 1981.

An old industry, the wood-turning industry developed during a time when the majority of household specialty items were manufactured from wood. Early records show that the wood-turning industry was firmly entrenched at the turn of the century, and that by the early 1940's, the industry was located primarily where it is today (Coolidge 1963). Many of the markets have disappeared, but an abundant supply of timber suitable for turnstock remains statewide, even though there have been some declines in quality.

Supply of Roundwood for Wood Turning

A previous analysis (Kingsley 1973) showed that 18 percent of the total growing-stock volume of sugar maple, yellow birch, paper birch, and beech was suitable for turnstock. We found that during 1981, almost 27 percent of the total growing-stock volume in these same four species plus red maple, ash, and aspen, was suitable for turnstock. Approximately 1.7 billion cubic feet (19.7 million cords) of growing stock in these selected hardwood species are hypothetically available to be harvested for turnstock in Maine (Table 2), many times more than the volume that is currently being harvested from these species.

Sugar maple contains the largest volume of any of the species suitable for turnstock; aspen is a close second. Both species account for 42 percent of the total growing-stock volume. Two important species to the wood-turning industry—paper birch and yellow birch—rank much lower.

We compared the growing-stock volume suitable for wood turning with the volume harvested for turnstock in 1981, for a number of selected hardwood species. Figure 2 shows this comparison (note that while the volumes are both expressed in millions of cubic feet, the scales of the axes are different). The volume harvested for each species is considerably less than the supply of each species, no species is being harvested at a level even approaching its supply. Only paper birch, with 3.1 million cubic feet (36.3 thousand cords) harvested, and a supply of 262.4 million cubic feet (3.1 million cords), is being harvested at a rate greater than 1 percent.

Figure 2.—Growing-stock volume suitable for turnstock on timberlands and volume of roundwood harvested from timberlands for turnstock by selected hardwood species, Maine, 1982.

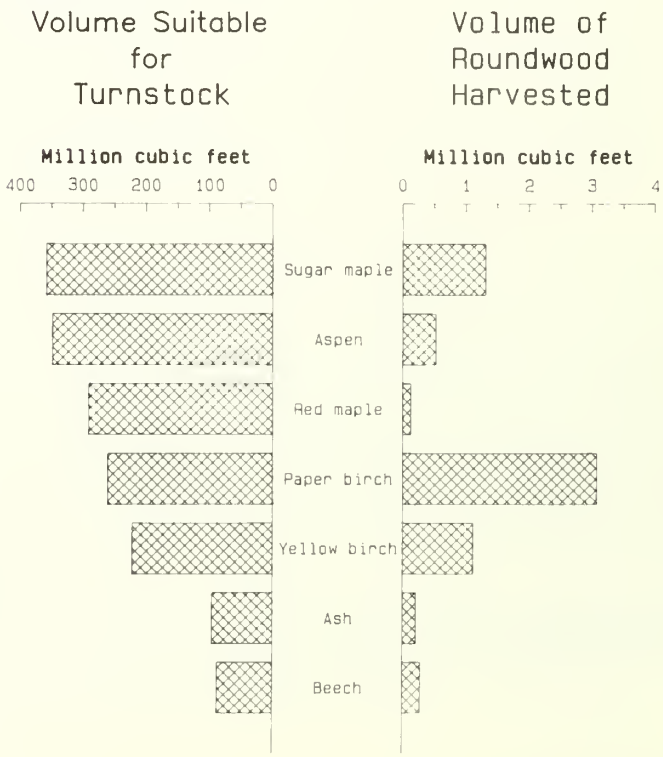


Table 2.—Net growing-stock volume of selected hardwood species suitable for turnstock on timberland by county and species, Maine, 1982

County	Red maple	Sugar maple	Yellow birch	Paper birch	Beech	Ash[a]	Aspen[b]	All species
	Million cubic feet							
Androscoggin	2.6	.0	.0	1.8	.8	.9	9.6	15.7
Aroostook	39.5	133.5	51.0	22.6	34.2	7.4	70.5	358.7
Cumberland	4.3	.0	1.2	4.5	1.5	2.3	1.4	15.2
Franklin	38.2	24.7	20.8	54.7	1.0	18.9	30.6	188.9
Hancock	4.1	.0	.0	4.6	.0	4.3	5.6	18.6
Kennebec	9.5	.2	1.3	6.1	1.9	7.6	9.9	36.5
Knox	1.4	.0	.0	1.9	.0	1.4	.0	4.7
Lincoln	2.2	.0	.0	1.4	.0	1.0	1.6	6.2
Oxford	31.5	16.3	34.6	42.1	12.6	15.5	33.8	186.4
Penobscot	32.9	32.4	10.2	16.1	1.5	5.6	40.8	139.5
Piscataquis	52.6	65.6	38.7	29.7	20.5	12.0	75.0	294.1
Sagadahoc	.8	.0	.0	.4	.0	1.3	.6	3.1
Somerset	35.3	80.6	56.5	34.5	10.0	8.2	36.3	261.4
Waldo	7.2	1.9	.5	4.9	.0	4.4	8.7	27.6
Washington	21.6	2.5	6.6	30.1	3.3	3.9	20.1	88.1
York	9.0	1.3	2.0	7.0	1.4	2.3	5.2	28.2
All counties	292.7	359.0	223.4	262.4	88.7	97.0	349.7	1,672.9

[a]Includes white and green ash.
[b]Includes quaking aspen and bigtooth aspen; does not include poplar species.

A number of constraints limit the volume that is actually available; constraints include landowner attitudes toward harvesting, size of woodlots, accessibility, terrain condition, and tree-length harvesting for pulpwood. Even though volumes are high, these constraints are one reason that manufacturers of wood-turned products must look to timberlands outside of Maine to supply some of their needs.

Geographic Variation

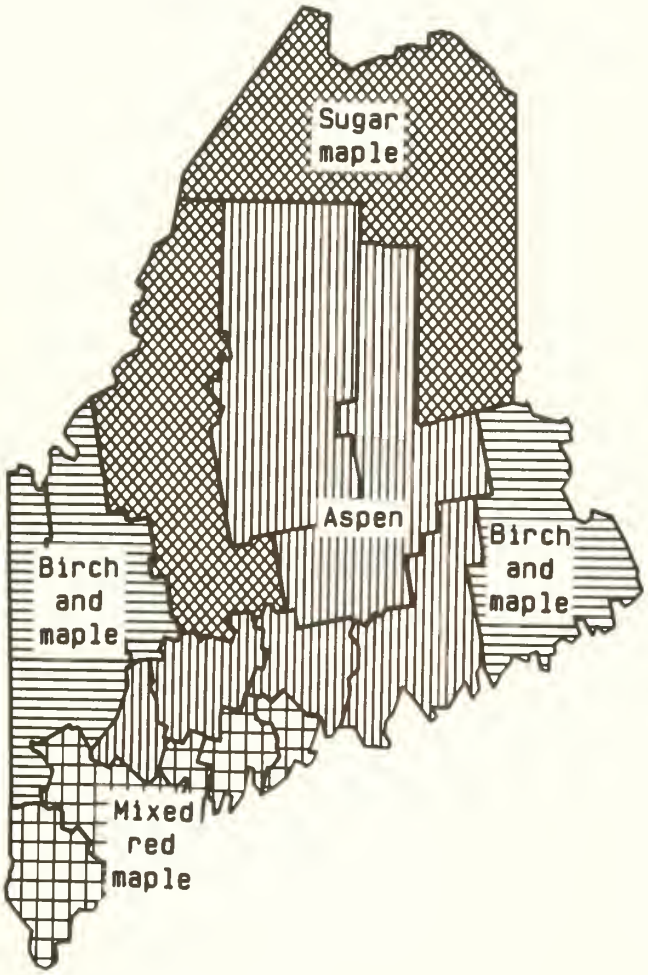
We developed detailed estimates of the timber suitable for turnstock at the county level (Appendix). To simplify our analysis, we segregated Maine into four regions, based on species that are suitable for wood turning. We called these regions birch-maple, sugar maple, aspen, and mixed red maple (Fig. 3).

Franklin, Oxford, and Washington Counties are located in the two birch-maple regions. The wood-turning industry settled in the western portion of Maine because paper birch and sugar maple are two of the three leading species in demand by the industry. There are 96.8 million cubic feet (1.1 million cords) of paper birch growing stock in Franklin and Oxford Counties, where 48 percent of the mills are located. That volume of paper birch is almost 37 percent of the total paper birch volume in the entire state.

Somerset and Aroostook Counties comprise the maple region; sugar maple alone predominates in these two counties. Here there are 214.1 million cubic feet (2.5 million cords) of sugar maple growing stock, or 60 percent of the total sugar maple growing-stock volume in Maine. Except for southern Somerset County, the bulk of this resource is located in remote locations far from population centers. Very little sugar maple is harvested from Aroostook County for wood turning because supplies of sugar maple are more readily available in western Maine, and transportation costs are prohibitive.

The remaining two regions are important in that they contain significant volumes of species suitable for wood turning, but these species are not preferred. Piscataquis and Penobscot Counties comprise the bulk of the aspen region. Hancock, Waldo, Kennebec, and Androscoggin Counties contain smaller but significant volumes of aspen. The counties throughout southwestern Maine (Knox, Lincoln, Sagadahoc, Cumberland, and York) contain a mixture of species important to the wood-turning industry. The common species is predominantly red maple.

Figure 3.—Regions of Maine based on the predominance of species suitable for turnstock.



Only 13 mills that manufacture a wood-turned product operate in the aspen and mixed red maple region, a small number of mills compared to the volume of timber acceptable for turnstock. For example, there are 158.4 million cubic feet (1.9 million cords) of aspen and 126.6 million cubic feet (1.5 million cords) of red maple growing-stock volume suitable for turnstock in these two regions. That is 45 percent of the total aspen volume and 43 percent of the total red maple volume in Maine. Much of this volume is close to population centers and possible markets.

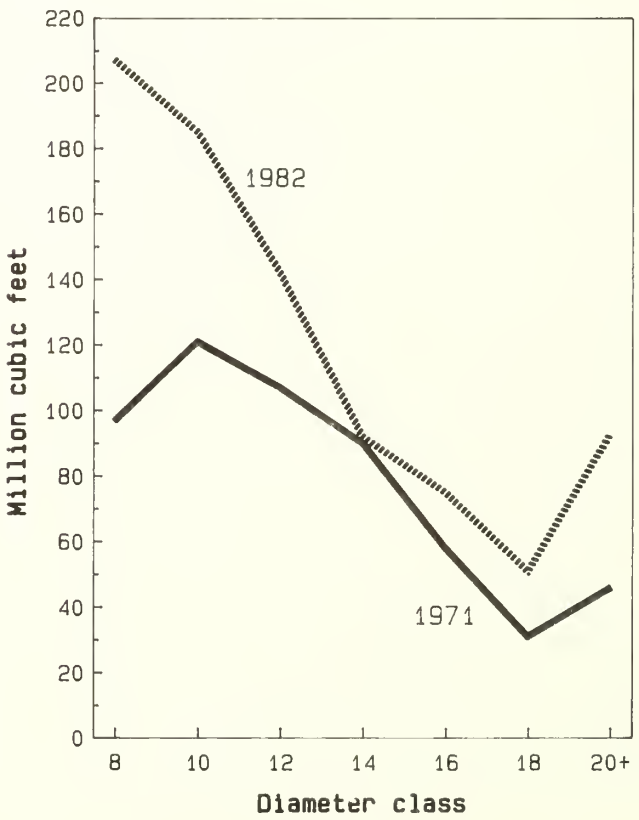
Many of the problems that faced the wood-turning industry in 1981 may have resulted from its dependence on only a few species. Adequate supplies of other species are available if the technology to use these species were commercially available and markets for end products using these species were developed. Red maple, for example, is in large supply, but used little.

Changes Over Time

Growing-stock volumes suitable for turnstock have increased since the last inventory. The three primary species used in the manufacture of wood-turned products—sugar maple, yellow birch, and paper birch—have increased from 550.2 million cubic feet (6.5 million cords) in 1971, to 844.8 million cubic feet (9.9 million cords) in 1982. A bright future for the wood-turning industry seems apparent, but underlying trends indicate disturbing problems.

Most of the increases in growing-stock volume have occurred in the smaller diameter classes: from the 8-inch to the 12-inch diameter classes. The important, larger diameter classes have shown only nominal increases (Fig. 4). These increases are not consistent with trends in the resource as a whole throughout the Northeast; curves of diameter-class distribution show a gradually maturing resource.

Figure 4.—Diameter-class distribution of growing stock for the primary hardwood species (sugar maple, yellow birch, and paper birch) suitable for turnstock in Maine, 1971 and 1982.



The greatest volume of timber suitable for turnstock in Maine occurs in the lowest diameter class, the 8-inch class. As more of the resource becomes comprised of smaller diameter trees, the quality of timber should decline, since grade is as much a function of tree size as condition of the tree bole. Table 3 shows that grade 2 and grade 3 material has remained essentially unchanged. Grade 1 material has decreased from 33 percent to 11 percent of the total, while construction log-grade material has increased from 6 percent to 21 percent of the total. Many smaller diameter trees are able to meet only construction log grade.

The distribution of volume by diameter class is similar throughout Maine. In most counties, the largest volumes occur in the smallest diameter classes. Only in Aroostook County and Somerset County are the greatest volumes found in the 12-inch diameter class; both counties fall in the sugar maple region. As mentioned previously, large volumes of sugar maple suitable for turnstock are available, yet these volumes are located in remote areas. For the most part, timber harvesters that supply wood-turning mills must select desirable trees from a scattered resource base.

Future of the Wood-turning Industry

In time, the resource should mature. Until then the industry will be hard pressed to avoid reducing supplies of timber below current levels, at least for sugar maple, yellow birch, and paper birch. Some manufacturers have begun to import a portion of their timber supplies, largely due to a decrease in the quality of these species, and a lack of markets in other states. The industry as a whole depends on certain select species, but there is no imminent danger that supplies will become depleted.

The species that are most important to the wood-turning industry in Maine are growing faster than they are being used. Figure 5 shows the growth and removals of sugar maple, yellow birch, and paper birch. As can be seen for each species, removals for all industrial forest products is less than growth. In fact, only sugar maple shows close to an equivalent rate of removals to growth, while paper birch removals are less than half its growth rate.

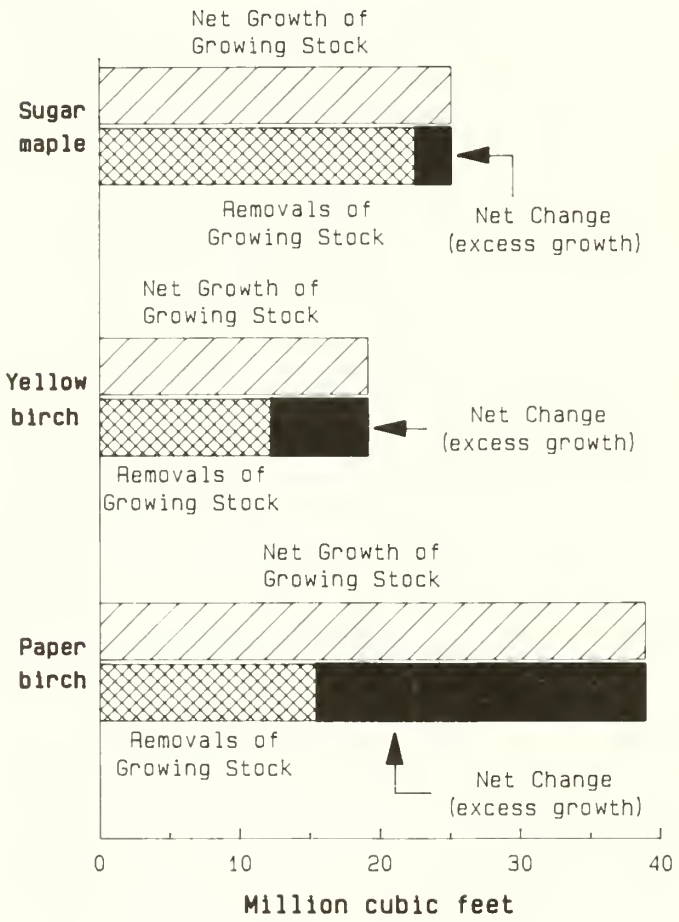
The danger of depleting supplies is more long-term in nature. Perhaps manufacturers of wood-turned products are just now beginning to feel the effects of this problem.

Table 3.—Net volume of sawtimber trees greater than 15.0 inches d.b.h. on timberland by species and standard-lumber log grade[a], Maine, 1971 and 1982

Species	Grade 1	Grade 2	Grade 3	Construction log	All grades
	Million board feet				
			1971		
Sugar maple	99.9	60.4	90.0	21.1	271.4
Yellow birch	70.3	60.8	100.1	8.4	239.6
Paper birch	19.9	14.7	23.2	4.6	62.4
All species	190.1	135.9	213.3	34.1	573.4
Percent	33	24	37	6	100
			1982		
Sugar maple	13.7	34.7	35.2	29.6	113.2
Yellow birch	28.5	99.3	156.5	82.6	366.9
Paper birch	21.8	31.7	32.6	6.4	92.5
All species	64.0	165.7	224.3	118.6	572.6
Percent	11	29	39	21	100

[a]Tree grades used in USDA Forest Service inventories are based on standard hardwood factory lumber grades developed by Vaughn, et al. (1966), and specifications for hardwood construction logs developed by Rast, et al. (1973). Grade specifications are applied to standing trees.

Figure 5.—Growth and removals of the primary hardwood species (sugar maple, yellow birch, and paper birch) used in the manufacture of wood-turned products in Maine, 1982.



Adequate supplies are available in general, but in local areas supplies may have become depleted, or simply locked up due to landowner constraints. If the industry is to maintain stability in the future, it must find ways to improve its utilization of nonpreferred species and lower grade material, since constraints currently imposed are not likely to improve.

Future declines in manufacturing for wood-turned products may come from outside sources, rather than any decrease of timber supplies. New England was once the center of the textile industry, with bobbin mills located throughout the region. Thirty years ago, 31 mills in New Hampshire and Vermont manufactured wood-turned products for the textile industry, today only 3 manufacture such products. When the textile industry moved south, the wood-turning industry lost many of its primary markets.

In the past, Maine may have remained unscathed because of the nature of its wood-turning industry. The bulk of the industry manufactured products for the furniture, tool, and novelty industry. During 1981, these secondary industries received more competition from plastic substitute products and foreign wood manufacturers.

Competition with manufacturers of plastic products is nothing new to the wood-turning industry. Such manufacturers have made inroads into the wood-turning industry in Maine over many years, and will probably continue to do so. The wood-turning industry has remained somewhat stable because some wood-based novelty and specialty products are preferred. Golfers prefer wooden tees because they do not shatter so easily on impact, and cigar smokers prefer wooden cigar tips because plastic tips tend to burn.

Cotton-tipped swabs are another example of a preferred wood-turned product. Plastic-stemmed swabs for consumer use have been on the market for a number of years; however, hospitals, which are an important market, prefer wooden swabs because they are easily sterilized. Markets that exist for these and similar products may always exist.

Competition from wood manufacturers abroad may most threaten the wood-turning industry in Maine. In some instances, wood from the United States is shipped overseas, where it is manufactured more cheaply. In other instances, foreign woods that are similar to accepted american woods are used. One such species is ramin (*Gonystylus bancanus*): a tropical wood found in Southeast Asia that is light-colored. It is used for furniture, mouldings, brush and broom handles, and toys (Rendle 1969).

Industry reports detailing United States' imports have been published quarterly by the U.S. Department of Commerce. Discontinued in 1982, these reports showed until then, that imports for a major wood-turned product such as dowel rods and pins rose between 1973 and 1980 (U.S. Department of Commerce 1979, 1982). Imports from the Pacific-rim countries of Japan, Indonesia, and Taiwan fluctuated, but increased from a low of 18 million lineal feet in 1973 to the highest point during that time period, 252 million lineal feet in 1979.

Since the cost of producing wood-turned products abroad is lower, foreign maufacturers can afford to sell their products at lower cost. These manufacturers have also been able to reduce costs of production by manufacturing a finished product. Goods shipped from overseas are more competitive because most manufacturers of wood-turned products in Maine produce items that are sent to establishments outside of the state to be assembled into the final finished product.

We believe that in the immediate future the wood-turning industry in Maine should remain relatively stable, much as it has for a number of decades. Supplies of timber are available to maintain and even promote growth in this industry. However, the industry's long-term future will hinge on its ability to: develop and implement technological improvements in processing, develop strategies to produce finished products, and identify new markets.

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Appendix

Methods and Specifications

Legislation passed by the United States Congress directs the USDA Forest Service to periodically collect resource information in every state of the Nation. The Forest Inventory and Analysis Unit of the Northeastern Forest Experiment Station collects this information in 14 northeastern states, which includes Maine. Since the original legislation, the forest resources of Maine have been measured three times: in 1958, 1971, and 1982.

The forest resource survey was conducted in the following manner: 62,801 pin-prick points were established on aerial photographs and classified into specific land-use and cubic-foot volume classes. A subsample of 2,475 plots were selected from this larger sample base and established on the ground. Field crews collected data on these field plots, and on 1,222 field plots established during earlier inventories.

The estimates of roundwood volume suitable for wood turning are a summary of information collected on the field plots. During the survey conducted in 1971 and the survey conducted in 1982, field crews collected information on the field plots that could be used to select trees suitable for turnstock. Specifications for selecting trees suitable for turnstock depended on (1) tree species, (2) evidence of rot in the tree bole, and (3) surface defects as evidence of sound wood in the tree bole.

Species was used to select trees suitable for turnstock because certain species are used by the wood-turning industry to the exclusion of all others. Paper birch, yellow birch, sugar maple, and beech were the most commonly used species of the wood-turning industry during the last survey. We included these four species in our analysis, but added red maple, ash, and aspen. The additional species were selected because they have been used more frequently by the wood-turning industry over the last decade.

Trees were also selected on both occasions by the condition of the tree bole. For turnstock, all rotten cull material in the tree bole is unacceptable. Most sound cull material is unacceptable because it will produce grade defect in the manufactured wood.

Some tree sections are used for boltwood if they contain usable wood to a 7-inch small-end diameter. We selected such trees that contained no rotten, and little sound cull material in the tree bole. To be selected, a tree must have had no more than 10 percent cull material in its bole, and all of this cull material must have been sound. Visual indicators of surface defect, such as knots and scars, were used to indicate unclear or unsound wood. A surface defect was assigned to each tree relating to the number of 2-foot clear cuttings in the first 16 feet of the tree bole. To be acceptable for turnstock, the tree must have had 8 clear feet.

An industry survey was conducted in conjunction with the resource survey, but only in 1982. The Maine Department of Conservation, Utilization and Marketing Division, assembled a list of all known primary wood manufacturing firms in Maine, firms that convert roundwood to wood products for industrial or consumer use. Those manufacturers that were operational during 1981 were asked to provide information on their wood consumption for that year, through a questionnaire mailed by the State. Possible out-of-state consumers of Maine roundwood were also sent questionnaires. Manufacturers who did not respond were contacted by telephone, resulting in a census of primary wood manufacturers.

The demand for wood-turned products was summarized from data collected for all wood manufacturers in Maine. Only those mills that converted roundwood to a turned-wood product, or that would be turned later, were used to analyze the production and consumption of roundwood for wood-turned products.

Definition of Terms

Forest land—Land that is at least 10 percent stocked with trees of any size, or that formerly had such tree cover and is not currently developed for nonforest use. The minimum area for classification of forest land is 1 acre.

Forest products—Roundwood supplied to primary manufacturing plants, or harvested for personal use.

Grade—A classification of the quality of sawtimber volume based on standard grades for factory lumber logs and standard specifications for hardwood construction logs, applied to standing trees.

Growing stock—The tree bole of live trees, 5.0 inches d.b.h. (diameter at breast height) or larger, that is presently or prospectively suitable for industrial forest products. Excludes species of typically small size, poor form, or inferior quality.

Growing-stock volume—Net volume, in cubic feet, of growing stock. Net volume equals gross volume, less deductions for cull.

Growth—The change, resulting from natural causes, in growing stock between inventories, divided by the number of growing seasons between inventories. Components of growth are accretion plus ingrowth minus cull increment and mortality. Accretion is the growth of growing stock between inventories; it does not include growth on trees cut between inventories, nor those trees that died. Ingrowth is the volume of growing stock that became 5.0 inches d.b.h. between inventories. Cull increment is the volume of growing stock from the previous inventory that became cull trees in the current inventory. Mortality is the volume of growing stock that died from natural causes between inventories.

Industrial forest products—Roundwood supplied to primary manufacturing plants. Does not include roundwood that has been harvested for personal use.

Primary wood manufacturers—Establishments that convert roundwood into wood products such as woodpulp, lumber, veneer, cooperage, and dimension products. The final product may be used as manufactured, or supplied to a secondary manufacturer.

Removals—Net growing-stock volume harvested or killed in logging, cultural operations, or land clearing. Also the net growing-stock volume growing on land that was reclassified from timberland to forest land withdrawn from utilization through administrative designation.

Roundwood—Logs, bolts, and other round timber generated by harvesting trees, or total tree chips.

Sawtimber—The tree sawlog of live trees, 9.0 inches d.b.h. or larger for softwoods and 11.0 inches d.b.h. or larger for hardwoods, containing at least one 12-foot sawlog or two noncontiguous 8-foot sawlogs, and meeting regional specifications for freedom from defect.

Sawtimber volume—Net volume, in board feet (International 1/4-inch rule), of sawtimber. Net volume equals gross volume less deductions for rot, sweep, and other defects that affect use for lumber.

Secondary wood manufacturers—Establishments that convert primary wood products such as woodpulp, lumber, veneer, cooperage, and dimension products into a finished product such as furniture or furniture parts, paper products, building materials, and so on.

Timberland—Forest land producing or capable of producing crops of industrial forest products (more than 20 cubic feet per acre per year) and not withdrawn from timber utilization.

Tree bole—The main stem of a tree between a 1-foot stump height and a 4-inch top d.o.b. (diameter outside bark), or until the main stem breaks into branches if that is before it reaches this top diameter.

Tree sawlog—The main stem of the tree between a 1-foot stump height and the sawlog top. The sawlog top is the point on the main stem above which a sawlog cannot be produced. The minimum sawlog top is 7.0 inches d.o.b. for softwoods and 9.0 inches d.o.b. for hardwoods, or until the main stem breaks into branches if that is before it reaches this top diameter.

Reliability of the Estimates

Tables in this appendix show the volume of selected hardwood species suitable for turnstock on timberland for each county, and include associated sampling errors for each estimate. The sampling errors are used as follows: the estimate of volume suitable for turnstock in Maine is 1,672.9 million cubic feet, but this estimate has an associated sampling error of 4.2 percent, or 70.3 million cubic feet. This means that if the survey were to be repeated, there is a 66 percent probability (2 to 1) that the resulting estimate would be 1,672.9 $\pm$ 70.3 million cubic feet, or between 1,602.6 and 1,743.2 million cubic feet; there is a 95 percent probability (19 to 1) that the estimate would be 1,672.9 $\pm$ 140.6 million cubic feet.

State-level estimates are more reliable beause they have the smallest sampling errors. As stated previously, the estimate of volume suitable for turnstock in Maine has a sampling error of 4.2 percent. The estimate of volume suitable for turnstock in Androscoggin County has a sampling error of 40.5 percent, or 15.7 $\pm$ 6.4 million cubic feet; county-level estimates are considerably less reliable than state-level estimates. In general, as the sample size used to derive an estimate decreases in relation to the total, the sampling error increases.

Some of the estimates presented in the tables have errors that are greater than 25 percent, and may not be reliable. An estimate with a sampling error of 50 percent or more would not be significantly different from zero at two standard deviations, and an estimate with an error between 25 and 50 percent would be suspect. Those estimates that have errors exceeding 25 percent should be used with caution.

To improve the reliability of the estimates, cell values may be combined. Data users may require combinations of counties, species, or diameter classes different from combinations that we may select. We have not attempted to combine any of the cell values with high sampling errors, but rather, have left that up to the discretion of the data user.

Combining cell values will not always reduce the sampling errors to acceptable levels. Sampling errors of combined estimates must be calculated to determine if the sampling errors have been reduced to acceptable levels. Because individual cell values are independent, the calculated sampling errors of combined cells will be approximations; they will underestimate the true sampling error, but will be sufficient to make judgments of acceptability. The technique to approximate the sampling errors of combined estimates is not difficult, and involves using the following formulas:

$$v(X_t) = (s_1X_1)^2 + (s_2X_2)^2 \quad (1)$$

$$s(X_t) = \sqrt{v(X_t)} / X_t \quad (2)$$

where;

X_1 = first cell-value estimate
X_2 = second cell-value estimate
X_t = combined cell-value estimate
s_1 = sampling error of first cell-value estimate
s_2 = sampling error of second cell-value estimate
$v(X_t)$ = variance of combined cell-value estimate
$s(X_t)$ = sampling error of combined cell-value estimate

The formulas are used as follows: The estimate of total volume suitable for turnstock in Androscoggin county is 15.7 million cubic feet, with a sampling error of 40.5 percent. This estimate has a high sampling error. Combining the estimate for Androscoggin county with the estimate of 15.2 million cubic feet for Cumberland county, which has an error of 22.2 percent, yields an estimate of 30.9 million cubic feet. The variance of this estimate is approximately 518,170.976 (using equation 1), and the sampling error associated with the combined estimate is 23.3 percent (using equation 2). As a general rule, the sampling error of a combined estimate will be approximately equal to or less than the smallest sampling error of the estimates that are to be combined.

County Tables

The following tables show the volume of selected hardwood species suitable for turnstock for each county in Maine. Sampling errors are shown with each table.

Table

4 Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, Androscoggin County, Maine, 1982.

5 Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, Aroostook County, Maine, 1982.

6 Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, Cumberland County, Maine, 1982.

7 Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, Franklin County, Maine, 1982.

8 Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, Hancock County, Maine, 1982.

9 Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, Kennebec County, Maine, 1982.

10 Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, Knox County, Maine, 1982.

11 Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, Lincoln County, Maine, 1982.

12 Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, Oxford County, Maine, 1982.

13 Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, Penobscot County, Maine, 1982.

14 Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, Piscataquis County, Maine, 1982.

15 Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, Sagadahoc County, Maine, 1982.

16 Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, Somerset County, Maine, 1982.

17 Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, Waldo County, Maine, 1982.

18 Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, Washington County, Maine, 1982.

19 Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, York County, Maine, 1982.

20 Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, Maine, 1982.

Table 4.—Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, Androscoggin County, Maine, 1982

Species	Diameter class (in inches)									All classes
	7.0–8.9	9.0–10.9	11.0–12.9	13.0–14.9	15.0–16.9	17.0–18.9	19.0–20.9	21.0–28.9	29.0 +	
	GROWING-STOCK VOLUME									
	Million cubic feet									
Red maple	.8	.5	1.0	.3	.0	.0	.0	.0	.0	2.6
Sugar maple	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Yellow birch	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Paper birch	1.2	.4	.2	.0	.0	.0	.0	.0	.0	1.8
Beech	.5	.3	.0	.0	.0	.0	.0	.0	.0	.8
Ash[a]	.5	.4	.0	.0	.0	.0	.0	.0	.0	.9
Aspen[b]	3.7	4.1	1.5	.3	.0	.0	.0	.0	.0	9.6
All species	6.7	5.7	2.7	.6	.0	.0	.0	.0	.0	15.7
	SAMPLING ERROR[c]									
	Percent									
Red maple	51.0	72.2	50.4	100.0	.0	.0	.0	.0	.0	34.8
Sugar maple	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Yellow birch	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Paper birch	53.0	100.0	100.0	.0	.0	.0	.0	.0	.0	42.5
Beech	71.2	100.0	.0	.0	.0	.0	.0	.0	.0	70.6
Ash[a]	75.4	100.0	.0	.0	.0	.0	.0	.0	.0	60.3
Aspen[b]	45.2	82.6	70.9	100.0	.0	.0	.0	.0	.0	60.0
All species	30.3	66.6	40.6	70.9	.0	.0	.0	.0	.0	40.5

[a]Includes white and green ash.

[b]Includes quaking aspen and bigtooth aspen; does not include poplar species.

[c]Sampling error is a measure of the reliability of an estimate, and is expressed as a percentage of the estimate. The sampling errors given here correspond to one standard deviation, and are calculated as the square root of the variance, divided by the estimate, and multiplied by 100. An estimate that has an associated sampling error greater than 25 percent, but less than 50 percent should be used with caution; an estimate that has an associated sampling error greater than or equal to 50 percent is not significantly different from zero, and is unreliable.

Table 5.—Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, Aroostook County, Maine, 1982

Species	Diameter class (in inches)									All classes
	7.0–8.9	9.0–10.9	11.0–12.9	13.0–14.9	15.0–16.9	17.0–18.9	19.0–20.9	21.0–28.9	29.0+	
	GROWING-STOCK VOLUME									
	Million cubic feet									
Red maple	6.8	6.2	9.7	10.7	2.5	3.6	.0	.0	.0	39.5
Sugar maple	14.1	18.5	19.7	20.1	15.8	17.2	12.1	12.2	3.8	133.5
Yellow birch	4.1	5.6	10.5	11.1	10.5	1.9	3.3	4.0	.0	51.0
Paper birch	5.9	6.6	7.6	.8	1.7	.0	.0	.0	.0	22.6
Beech	4.1	4.9	13.1	5.4	4.0	.0	.0	2.7	.0	34.2
Ash[a]	1.0	2.0	2.9	.0	.7	.0	.8	.0	.0	7.4
Aspen[b]	11.9	17.3	26.2	11.6	1.6	1.9	.0	.0	.0	70.5
All species	47.9	61.1	89.7	59.7	36.8	24.6	16.2	18.9	3.8	358.7
	SAMPLING ERROR[c]									
	Percent									
Red maple	30.2	33.1	24.7	30.0	58.1	58.0	.0	.0	.0	18.6
Sugar maple	23.8	23.7	20.5	19.7	23.7	26.5	42.0	55.5	100.0	13.9
Yellow birch	34.1	37.3	23.8	24.9	28.0	73.8	82.3	60.9	.0	14.2
Paper birch	39.5	40.1	31.0	100.0	70.8	.0	.0	.0	.0	23.5
Beech	42.1	42.7	25.2	37.6	50.6	.0	.0	100.0	.0	20.5
Ash[a]	71.5	57.7	45.4	.0	100.0	.0	100.0	.0	.0	31.5
Aspen[b]	33.8	29.2	18.3	27.4	70.8	71.5	.0	.0	.0	18.3
All species	13.7	12.9	9.7	13.0	15.9	21.7	36.9	40.5	100.0	7.9

[a]Includes white and green ash.

[b]Includes quaking aspen and bigtooth aspen; does not include poplar species.

[c]Sampling error is a measure of the reliability of an estimate, and is expressed as a percentage of the estimate. The sampling errors given here correspond to one standard deviation, and are calculated as the square root of the variance, divided by the estimate, and multiplied by 100. An estimate that has an associated sampling error greater than 25 percent, but less than 50 percent should be used with caution; an estimate that has an associated sampling error greater than or equal to 50 percent is not significantly different from zero, and is unreliable.

Table 6.—Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, Cumberland County, Maine, 1982

Species	Diameter class (in inches)									All classes
	7.0–8.9	9.0–10.9	11.0–12.9	13.0–14.9	15.0–16.9	17.0–18.9	19.0–20.9	21.0–28.9	29.0+	
	GROWING-STOCK VOLUME									
	Million cubic feet									
Red maple	2.1	.4	1.6	.2	.0	.0	.0	.0	.0	4.3
Sugar maple	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Yellow birch	.2	.6	.0	.4	.0	.0	.0	.0	.0	1.2
Paper birch	2.6	.7	.8	.4	.0	.0	.0	.0	.0	4.5
Beech	.0	.0	.8	.0	.0	.7	.0	.0	.0	1.5
Ash[a]	1.0	1.0	.2	.0	.0	.0	.0	.0	.0	2.2
Aspen[b]	.2	.7	.2	.3	.0	.0	.0	.0	.0	1.4
All species	6.1	3.4	3.6	1.3	.0	.7	.0	.0	.0	15.2
	SAMPLING ERROR[c]									
	Percent									
Red maple	39.4	100.0	42.9	100.0	.0	.0	.0	.0	.0	29.1
Sugar maple	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Yellow birch	100.0	69.6	.0	100.0	.0	.0	.0	.0	.0	49.5
Paper birch	37.1	70.9	56.6	100.0	.0	.0	.0	.0	.0	31.1
Beech	.0	.0	56.2	.0	.0	100.0	.0	.0	.0	53.9
Ash[a]	55.9	74.0	100.0	.0	.0	.0	.0	.0	.0	59.3
Aspen[b]	100.0	100.0	100.0	100.0	.0	.0	.0	.0	.0	56.8
All species	26.7	41.2	27.9	50.0	.0	100.0	.0	.0	.0	22.2

[a]Includes white and green ash.

[b]Includes quaking aspen and bigtooth aspen; does not include poplar species.

[c]Sampling error is a measure of the reliability of an estimate, and is expressed as a percentage of the estimate. The sampling errors given here correspond to one standard deviation, and are calculated as the square root of the variance, divided by the estimate, and multiplied by 100. An estimate that has an associated sampling error greater than 25 percent, but less than 50 percent should be used with caution; an estimate that has an associated sampling error greater than or equal to 50 percent is not significantly different from zero, and is unreliable.

Table 7.—Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, Franklin County, Maine, 1982

Species	Diameter class (in inches)									All classes
	7.0–8.9	9.0–10.9	11.0–12.9	13.0–14.9	15.0–16.9	17.0–18.9	19.0–20.9	21.0–28.9	29.0+	
	GROWING-STOCK VOLUME									
	Million cubic feet									
Red maple	14.2	9.9	8.7	2.5	.0	2.9	.0	.0	.0	38.2
Sugar maple	9.1	6.7	5.2	.9	.8	.0	2.0	.0	.0	24.7
Yellow birch	8.4	6.2	4.0	.9	1.3	.0	.0	.0	.0	20.8
Paper birch	27.9	15.2	7.0	2.3	1.4	.9	.0	.0	.0	54.7
Beech	.4	.6	.0	.0	.0	.0	.0	.0	.0	1.0
Ash[a]	7.1	5.7	2.4	2.6	.0	1.1	.0	.0	.0	18.9
Aspen[b]	11.2	5.4	11.0	.9	1.1	1.0	.0	.0	.0	30.6
All species	78.3	49.7	38.3	10.1	4.6	5.9	2.0	.0	.0	188.9
	SAMPLING ERROR[c]									
	Percent									
Red maple	26.8	38.9	41.0	57.5	.0	70.8	.0	.0	.0	28.4
Sugar maple	31.4	45.9	43.6	100.0	100.0	.0	100.0	.0	.0	34.6
Yellow birch	27.6	38.4	37.3	100.0	100.0	.0	.0	.0	.0	23.3
Paper birch	20.6	26.9	37.8	74.6	100.0	100.0	.0	.0	.0	19.1
Beech	100.0	100.0	.0	.0	.0	.0	.0	.0	.0	72.2
Ash[a]	45.3	52.4	75.5	73.4	.0	100.0	.0	.0	.0	42.2
Aspen[b]	67.2	51.8	40.6	100.0	100.0	100.0	.0	.0	.0	41.3
All species	15.0	18.5	19.1	37.3	50.2	44.8	100.0	.0	.0	13.3

[a]Includes white and green ash.

[b]Includes quaking aspen and bigtooth aspen; does not include poplar species.

[c]Sampling error is a measure of the reliability of an estimate, and is expressed as a percentage of the estimate. The sampling errors given here correspond to one standard deviation, and are calculated as the square root of the variance, divided by the estimate, and multiplied by 100. An estimate that has an associated sampling error greater than 25 percent, but less than 50 percent should be used with caution; an estimate that has an associated sampling error greater than or equal to 50 percent is not significantly different from zero, and is unreliable.

Table 8.—Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, Hancock County, Maine, 1982

Species	Diameter class (in inches)									All classes
	7.0–8.9	9.0–10.9	11.0–12.9	13.0–14.9	15.0–16.9	17.0–18.9	19.0–20.9	21.0–28.9	29.0+	
	GROWING-STOCK VOLUME									
	Million cubic feet									
Red maple	.0	.7	2.4	.0	1.0	.0	.0	.0	.0	4.1
Sugar maple	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Yellow birch	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Paper birch	.9	2.4	1.3	.0	.0	.0	.0	.0	.0	4.6
Beech	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Ash[a]	.4	1.5	1.0	1.4	.0	.0	.0	.0	.0	4.3
Aspen[b]	1.8	2.4	.5	.9	.0	.0	.0	.0	.0	5.6
All species	3.1	7.0	5.2	2.3	1.0	.0	.0	.0	.0	18.6
	SAMPLING ERROR[c]									
	Percent									
Red maple	.0	100.0	54.5	.0	100.0	.0	.0	.0	.0	43.2
Sugar maple	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Yellow birch	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Paper birch	100.0	57.7	70.1	.0	.0	.0	.0	.0	.0	48.5
Beech	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Ash[a]	100.0	70.4	100.0	100.0	.0	.0	.0	.0	.0	74.4
Aspen[b]	100.0	74.3	43.8	100.0	100.0	.0	.0	.0	.0	57.7
All species	65.7	42.8	43.8	73.0	100.0	.0	.0	.0	.0	38.7

[a]Includes white and green ash.

[b]Includes quaking aspen and bigtooth aspen; does not include poplar species.

[c]Sampling error is a measure of the reliability of an estimate, and is expressed as a percentage of the estimate. The sampling errors given here correspond to one standard deviation, and are calculated as the square root of the variance, divided by the estimate, and multiplied by 100. An estimate that has an associated sampling error greater than 25 percent, but less than 50 percent should be used with caution; an estimate that has an associated sampling error greater than or equal to 50 percent is not significantly different from zero, and is unreliable.

Table 9.—Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, Kennebec County, Maine, 1982

Species	Diameter class (in inches)									All classes
	7.0–8.9	9.0–10.9	11.0–12.9	13.0–14.9	15.0–16.9	17.0–18.9	19.0–20.9	21.0–28.9	29.0+	
	GROWING-STOCK VOLUME									
	Million cubic feet									
Red maple	3.2	2.9	3.0	.4	.0	.0	.0	.0	.0	9.5
Sugar maple	.0	.0	.2	.0	.0	.0	.0	.0	.0	.2
Yellow birch	.3	.4	.0	.6	.0	.0	.0	.0	.0	1.3
Paper birch	2.9	1.7	1.5	.0	.0	.0	.0	.0	.0	6.1
Beech	.6	1.3	.0	.0	.0	.0	.0	.0	.0	1.9
Ash[a]	2.4	3.3	.3	.7	.5	.0	.0	.4	.0	7.6
Aspen[b]	4.2	2.7	2.1	.0	.9	.0	.0	.0	.0	9.9
All species	13.6	12.3	7.1	1.7	1.4	.0	.0	.4	.0	36.5
	SAMPLING ERROR[c]									
	Percent									
Red maple	33.9	50.0	51.1	100.0	.0	.0	.0	.0	.0	37.4
Sugar maple	.0	.0	100.0	.0	.0	.0	.0	.0	.0	100.0
Yellow birch	70.9	100.0	.0	71.3	.0	.0	.0	.0	.0	67.6
Paper birch	41.5	45.4	53.1	.0	.0	.0	.0	.0	.0	28.1
Beech	59.2	81.1	.0	.0	.0	.0	.0	.0	.0	71.3
Ash[a]	41.4	34.7	100.0	70.7	100.0	.0	.0	100.0	.0	31.2
Aspen[b]	28.9	34.1	48.1	.0	71.2	.0	.0	.0	.0	22.4
All species	18.4	21.0	30.9	44.7	57.2	.0	.0	100.0	.0	15.8

[a]Includes white and green ash.

[b]Includes quaking aspen and bigtooth aspen; does not include poplar species.

[c]Sampling error is a measure of the reliability of an estimate, and is expressed as a percentage of the estimate. The sampling errors given here correspond to one standard deviation, and are calculated as the square root of the variance, divided by the estimate, and multiplied by 100. An estimate that has an associated sampling error greater than 25 percent, but less than 50 percent should be used with caution; an estimate that has an associated sampling error greater than or equal to 50 percent is not significantly different from zero, and is unreliable.

Table 10.—Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, Knox County, Maine, 1982

Species	Diameter class (in inches)									All classes
	7.0–8.9	9.0–10.9	11.0–12.9	13.0–14.9	15.0–16.9	17.0–18.9	19.0–20.9	21.0–28.9	29.0+	
	GROWING-STOCK VOLUME									
	Million cubic feet									
Red maple	.3	.0	.6	.0	.0	.5	.0	.0	.0	1.4
Sugar maple	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Yellow birch	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Paper birch	.8	.7	.2	.2	.0	.0	.0	.0	.0	1.9
Beech	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Ash[a]	.0	.7	.0	.0	.0	.7	.0	.0	.0	1.4
Aspen[b]	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
All species	1.1	1.4	.8	.2	.0	1.2	.0	.0	.0	4.7
	SAMPLING ERROR[c]									
	Percent									
Red maple	100.0	.0	100.0	.0	.0	100.0	.0	.0	.0	71.9
Sugar maple	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Yellow birch	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Paper birch	73.9	100.0	100.0	100.0	.0	.0	.0	.0	.0	65.0
Beech	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Ash[a]	.0	100.0	.0	.0	.0	100.0	.0	.0	.0	70.7
Aspen[b]	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
All species	59.5	68.3	76.4	100.0	.0	72.3	.0	.0	.0	39.1

[a]Includes white and green ash.

[b]Includes quaking aspen and bigtooth aspen; does not include poplar species.

[c]Sampling error is a measure of the reliability of an estimate, and is expressed as a percentage of the estimate. The sampling errors given here correspond to one standard deviation, and are calculated as the square root of the variance, divided by the estimate, and multiplied by 100. An estimate that has an associated sampling error greater than 25 percent, but less than 50 percent should be used with caution; an estimate that has an associated sampling error greater than or equal to 50 percent is not significantly different from zero, and is unreliable.

Table 11.—Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, Lincoln County, Maine, 1982

Species	Diameter class (in inches)									All classes
	7.0–8.9	9.0–10.9	11.0–12.9	13.0–14.9	15.0–16.9	17.0–18.9	19.0–20.9	21.0–28.9	29.0+	
	GROWING-STOCK VOLUME									
	Million cubic feet									
Red maple	1.5	.3	.4	.0	.0	.0	.0	.0	.0	2.2
Sugar maple	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Yellow birch	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Paper birch	.3	.3	.8	.0	.0	.0	.0	.0	.0	1.4
Beech	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Ash[a]	1.0	.0	.0	.0	.0	.0	.0	.0	.0	1.0
Aspen[b]	1.3	.3	.0	.0	.0	.0	.0	.0	.0	1.6
All species	4.1	.9	1.2	.0	.0	.0	.0	.0	.0	6.2
	SAMPLING ERROR[c]									
	Percent									
Red maple	49.7	100.0	70.7	.0	.0	.0	.0	.0	.0	38.4
Sugar maple	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Yellow birch	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Paper birch	100.0	100.0	74.8	.0	.0	.0	.0	.0	.0	70.3
Beech	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Ash[a]	70.9	.0	.0	.0	.0	.0	.0	.0	.0	70.9
Aspen[b]	61.3	100.0	.0	.0	.0	.0	.0	.0	.0	51.5
All species	29.2	56.9	59.8	.0	.0	.0	.0	.0	.0	26.6

[a]Includes white and green ash.

[b]Includes quaking aspen and bigtooth aspen; does not include poplar species.

[c]Sampling error is a measure of the reliability of an estimate, and is expressed as a percentage of the estimate. The sampling errors given here correspond to one standard deviation, and are calculated as the square root of the variance, divided by the estimate, and multiplied by 100. An estimate that has an associated sampling error greater than 25 percent, but less than 50 percent should be used with caution; an estimate that has an associated sampling error greater than or equal to 50 percent is not significantly different from zero, and is unreliable.

Table 12.—Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, Oxford County, Maine, 1982

Species	Diameter class (in inches)									All classes
	7.0–8.9	9.0–10.9	11.0–12.9	13.0–14.9	15.0–16.9	17.0–18.9	19.0–20.9	21.0–28.9	29.0 +	
	GROWING-STOCK VOLUME									
	Million cubic feet									
Red maple	13.1	11.5	1.6	2.9	.0	1.3	1.1	.0	.0	31.5
Sugar maple	6.2	3.6	3.1	1.1	1.2	1.1	.0	.0	.0	16.3
Yellow birch	5.4	11.0	5.5	3.3	1.4	3.0	1.9	3.1	.0	34.6
Paper birch	18.4	17.4	3.5	1.9	.0	.9	.0	.0	.0	42.1
Beech	6.1	3.5	3.0	.0	.0	.0	.0	.0	.0	12.6
Ash[a]	2.7	2.5	.6	1.0	.0	2.2	2.6	3.9	.0	15.5
Aspen[b]	14.1	14.5	3.4	1.8	.0	.0	.0	.0	.0	33.8
All species	66.0	64.0	20.7	12.0	2.6	8.5	5.6	7.0	.0	186.4
	SAMPLING ERROR[c]									
	Percent									
Red maple	25.1	36.0	56.6	72.9	.0	100.0	100.0	.0	.0	28.7
Sugar maple	35.7	49.6	65.4	100.0	100.0	100.0	.0	.0	.0	29.6
Yellow birch	44.2	48.7	40.6	49.2	100.0	70.7	100.0	100.0	.0	31.3
Paper birch	28.6	25.9	53.8	70.8	.0	100.0	.0	.0	.0	22.3
Beech	73.7	50.1	49.6	.0	.0	.0	.0	.0	.0	52.3
Ash[a]	51.0	77.6	100.0	100.0	.0	100.0	100.0	100.0	.0	70.1
Aspen[b]	35.7	47.0	44.2	70.0	.0	.0	.0	.0	.0	33.7
All species	16.7	18.4	22.8	30.5	70.8	41.7	60.7	71.1	.0	14.8

[a]Includes white and green ash.

[b]Includes quaking aspen and bigtooth aspen; does not include poplar species.

[c]Sampling error is a measure of the reliability of an estimate, and is expressed as a percentage of the estimate. The sampling errors given here correspond to one standard deviation, and are calculated as the square root of the variance, divided by the estimate, and multiplied by 100. An estimate that has an associated sampling error greater than 25 percent, but less than 50 percent should be used with caution; an estimate that has an associated sampling error greater than or equal to 50 percent is not significantly different from zero, and is unreliable.

Table 13.—Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, Penobscot County, Maine, 1982

Species	Diameter class (in inches)									All classes
	7.0–8.9	9.0–10.9	11.0–12.9	13.0–14.9	15.0–16.9	17.0–18.9	19.0–20.9	21.0–28.9	29.0 +	
	GROWING-STOCK VOLUME									
	Million cubic feet									
Red maple	10.1	8.0	5.1	4.1	.9	4.7	.0	.0	.0	32.9
Sugar maple	8.1	8.1	3.5	3.6	.9	3.5	2.7	2.0	.0	32.4
Yellow birch	3.6	5.3	.4	.0	.9	.0	.0	.0	.0	10.2
Paper birch	6.6	3.1	3.9	2.5	.0	.0	.0	.0	.0	16.1
Beech	1.0	.0	.0	.5	.0	.0	.0	.0	.0	1.5
Ash[a]	2.6	1.6	.4	.0	.0	.0	.0	1.0	.0	5.6
Aspen[b]	11.0	10.9	8.4	10.5	.0	.0	.0	.0	.0	40.8
All species	43.0	37.0	21.7	21.2	2.7	8.2	2.7	3.0	.0	139.5
	SAMPLING ERROR[c]									
	Percent									
Red maple	23.0	37.6	33.4	44.1	100.0	71.9	.0	.0	.0	19.2
Sugar maple	40.5	36.6	45.2	50.4	100.0	76.7	100.0	70.7	.0	24.5
Yellow birch	55.5	51.2	100.0	.0	100.0	.0	.0	.0	.0	46.9
Paper birch	50.2	49.8	52.7	57.4	.0	.0	.0	.0	.0	31.1
Beech	72.5	.0	.0	100.0	.0	.0	.0	.0	.0	58.5
Ash[a]	73.5	70.7	100.0	.0	.0	.0	.0	100.0	.0	48.9
Aspen[b]	35.4	38.3	31.0	37.0	.0	.0	.0	.0	.0	26.3
All species	17.9	18.8	19.4	25.1	57.5	52.6	100.0	57.6	.0	12.5

[a]Includes white and green ash.

[b]Includes quaking aspen and bigtooth aspen; does not include poplar species.

[c]Sampling error is a measure of the reliability of an estimate, and is expressed as a percentage of the estimate. The sampling errors given here correspond to one standard deviation, and are calculated as the square root of the variance, divided by the estimate, and multiplied by 100. An estimate that has an associated sampling error greater than 25 percent, but less than 50 percent should be used with caution; an estimate that has an associated sampling error greater than or equal to 50 percent is not significantly different from zero, and is unreliable.

Table 14.—Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, Piscataquis County, Maine, 1982

Species	Diameter class (in inches)									All classes
	7.0–8.9	9.0–10.9	11.0–12.9	13.0–14.9	15.0–16.9	17.0–18.9	19.0–20.9	21.0–28.9	29.0+	
	GROWING-STOCK VOLUME									
	Million cubic feet									
Red maple	18.1	11.7	11.5	1.8	7.5	1.0	.0	1.0	.0	52.6
Sugar maple	9.4	10.5	11.3	5.5	5.2	11.0	8.7	4.0	.0	65.6
Yellow birch	4.6	7.9	5.1	3.5	9.7	3.7	.8	3.4	.0	38.7
Paper birch	9.4	9.6	4.2	1.7	4.8	.0	.0	.0	.0	29.7
Beech	3.2	4.3	6.3	3.5	2.2	1.0	.0	.0	.0	20.5
Ash[a]	6.7	2.8	1.2	.0	1.3	.0	.0	.0	.0	12.0
Aspen[b]	20.4	21.0	9.5	8.2	8.4	2.2	4.0	1.3	.0	75.0
All species	71.8	67.8	49.1	24.2	39.1	18.9	13.5	9.7	.0	294.1
	SAMPLING ERROR[c]									
	Percent									
Red maple	24.4	27.9	24.0	71.3	38.3	100.0	.0	100.0	.0	16.7
Sugar maple	45.1	31.9	30.2	40.7	44.7	41.2	52.5	61.5	.0	20.6
Yellow birch	36.9	31.6	33.0	44.5	36.7	59.8	100.0	76.7	.0	18.2
Paper birch	27.2	36.7	41.3	70.3	53.2	.0	.0	.0	.0	22.9
Beech	42.3	44.8	42.8	57.8	71.1	100.0	.0	.0	.0	24.9
Ash[a]	48.4	57.1	70.7	.0	100.0	.0	.0	.0	.0	41.9
Aspen[b]	39.7	39.7	37.7	38.6	50.9	70.7	70.7	100.0	.0	25.6
All species	17.4	16.2	15.0	21.0	19.9	28.5	39.9	42.6	.0	10.4

[a]Includes white and green ash.

[b]Includes quaking aspen and bigtooth aspen; does not include poplar species.

[c]Sampling error is a measure of the reliability of an estimate, and is expressed as a percentage of the estimate. The sampling errors given here correspond to one standard deviation, and are calculated as the square root of the variance, divided by the estimate, and multiplied by 100. An estimate that has an associated sampling error greater than 25 percent, but less than 50 percent should be used with caution; an estimate that has an associated sampling error greater than or equal to 50 percent is not significantly different from zero, and is unreliable.

Table 15.—Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, Sagadahoc County, Maine, 1982

Species	Diameter class (in inches)									All classes
	7.0–8.9	9.0–10.9	11.0–12.9	13.0–14.9	15.0–16.9	17.0–18.9	19.0–20.9	21.0–28.9	29.0+	
	GROWING-STOCK VOLUME									
	Million cubic feet									
Red maple	.6	.0	.2	.0	.0	.0	.0	.0	.0	.8
Sugar maple	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Yellow birch	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Paper birch	.0	.4	.0	.0	.0	.0	.0	.0	.0	.4
Beech	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Ash[a]	.6	.7	.0	.0	.0	.0	.0	.0	.0	1.3
Aspen[b]	.3	.3	.0	.0	.0	.0	.0	.0	.0	.6
All species	1.5	1.4	.2	.0	.0	.0	.0	.0	.0	3.1
	SAMPLING ERROR[c]									
	Percent									
Red maple	68.8	.0	100.0	.0	.0	.0	.0	.0	.0	55.0
Sugar maple	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Yellow birch	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Paper birch	.0	100.0	.0	.0	.0	.0	.0	.0	.0	100.0
Beech	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Ash[a]	68.8	100.0	.0	.0	.0	.0	.0	.0	.0	78.5
Aspen[b]	100.0	100.0	.0	.0	.0	.0	.0	.0	.0	68.8
All species	39.7	78.1	100.0	.0	.0	.0	.0	.0	.0	45.2

[a]Includes white and green ash.

[b]Includes quaking aspen and bigtooth aspen; does not include poplar species.

[c]Sampling error is a measure of the reliability of an estimate, and is expressed as a percentage of the estimate. The sampling errors given here correspond to one standard deviation, and are calculated as the square root of the variance, divided by the estimate, and multiplied by 100. An estimate that has an associated sampling error greater than 25 percent, but less than 50 percent should be used with caution; an estimate that has an associated sampling error greater than or equal to 50 percent is not significantly different from zero, and is unreliable.

Table 16.—Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, Somerset County, Maine, 1982

Species	Diameter class (in inches)									All classes
	7.0–8.9	9.0–10.9	11.0–12.9	13.0–14.9	15.0–16.9	17.0–18.9	19.0–20.9	21.0–28.9	29.0+	
	GROWING-STOCK VOLUME									
	Million cubic feet									
Red maple	6.4	12.9	4.2	3.1	2.3	2.6	3.8	.0	.0	35.3
Sugar maple	9.4	13.3	16.5	14.5	8.6	3.0	5.5	9.8	.0	80.6
Yellow birch	5.4	8.4	7.8	8.9	6.8	4.9	5.4	8.9	.0	56.5
Paper birch	12.5	6.1	10.2	4.5	1.2	.0	.0	.0	.0	34.5
Beech	1.9	.0	5.3	.0	1.3	1.5	.0	.0	.0	10.0
Ash[a]	2.1	4.4	1.7	.0	.0	.0	.0	.0	.0	8.2
Aspen[b]	5.7	7.5	8.4	6.1	3.4	3.3	1.9	.0	.0	36.3
All species	43.4	52.6	54.1	37.1	23.6	15.3	16.6	18.7	.0	261.4
	SAMPLING ERROR[c]									
	Percent									
Red maple	35.1	36.4	41.5	50.3	70.7	71.0	70.4	.0	.0	24.8
Sugar maple	31.3	28.4	26.5	28.3	61.5	70.7	61.2	42.5	.0	21.8
Yellow birch	35.4	32.4	28.6	28.3	44.3	58.0	52.2	66.6	.0	19.9
Paper birch	29.2	35.2	37.1	62.3	100.0	100.0	.0	.0	.0	24.8
Beech	61.7	.0	44.0	.0	100.0	100.0	.0	.0	.0	35.0
Ash[a]	60.7	59.1	58.8	.0	.0	.0	.0	.0	.0	43.1
Aspen[b]	58.3	51.6	43.0	43.3	57.8	71.7	100.0	.0	.0	33.4
All species	16.3	16.2	15.0	17.4	30.4	30.9	32.5	38.3	.0	12.0

[a]Includes white and green ash.

[b]Includes quaking aspen and bigtooth aspen; does not include poplar species.

[c]Sampling error is a measure of the reliability of an estimate, and is expressed as a percentage of the estimate. The sampling errors given here correspond to one standard deviation, and are calculated as the square root of the variance, divided by the estimate, and multiplied by 100. An estimate that has an associated sampling error greater than 25 percent, but less than 50 percent should be used with caution; an estimate that has an associated sampling error greater than or equal to 50 percent is not significantly different from zero, and is unreliable.

Table 17.—Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, Waldo County, Maine, 1982

Species	Diameter class (in inches)									All classes
	7.0–8.9	9.0–10.9	11.0–12.9	13.0–14.9	15.0–16.9	17.0–18.9	19.0–20.9	21.0–28.9	29.0+	
	GROWING-STOCK VOLUME									
	Million cubic feet									
Red maple	2.5	1.5	2.1	.7	.4	.0	.0	.0	.0	7.2
Sugar maple	1.4	.3	.2	.0	.0	.0	.0	.0	.0	1.9
Yellow birch	.5	.0	.0	.0	.0	.0	.0	.0	.0	.5
Paper birch	2.9	1.1	.9	.0	.0	.0	.0	.0	.0	4.9
Beech	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Ash[a]	2.3	.3	.3	.4	.0	1.1	.0	.0	.0	4.4
Aspen[b]	1.9	5.6	1.2	.0	.0	.0	.0	.0	.0	8.7
All species	11.5	8.8	4.7	1.1	.4	1.1	.0	.0	.0	27.6
	SAMPLING ERROR[c]									
	Percent									
Red maple	35.0	52.5	51.6	70.8	100.0	.0	.0	.0	.0	31.2
Sugar maple	51.0	100.0	100.0	.0	.0	.0	.0	.0	.0	41.5
Yellow birch	80.1	.0	.0	.0	.0	.0	.0	.0	.0	80.1
Paper birch	36.0	50.4	49.8	.0	.0	.0	.0	.0	.0	31.4
Beech	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Ash[a]	47.8	100.0	100.0	100.0	.0	72.6	.0	.0	.0	46.8
Aspen[b]	45.1	51.5	43.6	.0	.0	.0	.0	.0	.0	44.2
All species	20.3	34.9	27.8	56.1	100.0	72.6	.0	.0	.0	19.1

[a]Includes white and green ash.

[b]Includes quaking aspen and bigtooth aspen; does not include poplar species.

[c]Sampling error is a measure of the reliability of an estimate, and is expressed as a percentage of the estimate. The sampling errors given here correspond to one standard deviation, and are calculated as the square root of the variance, divided by the estimate, and multiplied by 100. An estimate that has an associated sampling error greater than 25 percent, but less than 50 percent should be used with caution; an estimate that has an associated sampling error greater than or equal to 50 percent is not significantly different from zero, and is unreliable.

Table 18.—Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, Washington County, Maine, 1982

Species	Diameter class (in inches)									All classes
	7.0–8.9	9.0–10.9	11.0–12.9	13.0–14.9	15.0–16.9	17.0–18.9	19.0–20.9	21.0–28.9	29.0+	
	GROWING-STOCK VOLUME									
	Million cubic feet									
Red maple	10.4	3.8	5.5	1.9	.0	.0	.0	.0	.0	21.6
Sugar maple	.4	.8	1.3	.0	.0	.0	.0	.0	.0	2.5
Yellow birch	3.8	1.5	.6	.7	.0	.0	.0	.0	.0	6.6
Paper birch	14.2	7.7	3.6	2.2	2.4	.0	.0	.0	.0	30.1
Beech	.5	.0	.7	.8	1.3	.0	.0	.0	.0	3.3
Ash[a]	2.0	1.9	.0	.0	.0	.0	.0	.0	.0	3.9
Aspen[b]	6.2	2.8	4.4	5.3	1.4	.0	.0	.0	.0	20.1
All species	37.5	18.5	16.1	10.9	5.1	.0	.0	.0	.0	88.1
	SAMPLING ERROR[c]									
	Percent									
Red maple	31.2	64.1	43.1	70.7	.0	.0	.0	.0	.0	27.2
Sugar maple	100.0	100.0	100.0	.0	.0	.0	.0	.0	.0	84.8
Yellow birch	51.6	70.0	100.0	100.0	.0	.0	.0	.0	.0	36.8
Paper birch	25.9	36.2	52.4	100.0	69.9	.0	.0	.0	.0	24.2
Beech	100.0	.0	100.0	100.0	100.0	.0	.0	.0	.0	86.0
Ash[a]	61.9	70.9	.0	.0	.0	.0	.0	.0	.0	60.4
Aspen[b]	45.3	57.4	49.0	66.0	100.0	.0	.0	.0	.0	41.4
All species	17.6	26.1	30.2	39.6	49.5	.0	.0	.0	.0	17.6

[a]Includes white and green ash.

[b]Includes quaking aspen and bigtooth aspen; does not include poplar species.

[c]Sampling error is a measure of the reliability of an estimate, and is expressed as a percentage of the estimate. The sampling errors given here correspond to one standard deviation, and are calculated as the square root of the variance, divided by the estimate, and multiplied by 100. An estimate that has an associated sampling error greater than 25 percent, but less than 50 percent should be used with caution; an estimate that has an associated sampling error greater than or equal to 50 percent is not significantly different from zero, and is unreliable.

Table 19.—Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, York County, Maine, 1982

Species	Diameter class (in inches)									All classes
	7.0–8.9	9.0–10.9	11.0–12.9	13.0–14.9	15.0–16.9	17.0–18.9	19.0–20.9	21.0–28.9	29.0+	
	GROWING-STOCK VOLUME									
	Million cubic feet									
Red maple	4.1	2.9	1.1	.9	.0	.0	.0	.0	.0	9.0
Sugar maple	1.1	.0	.2	.0	.0	.0	.0	.0	.0	1.3
Yellow birch	1.4	.4	.2	.0	.0	.0	.0	.0	.0	2.0
Paper birch	3.1	2.4	1.1	.4	.0	.0	.0	.0	.0	7.0
Beech	.8	.3	.3	.0	.0	.0	.0	.0	.0	1.4
Ash[a]	1.2	.0	.2	.0	.0	.4	.5	.0	.0	2.3
Aspen[b]	1.7	3.0	.5	.0	.0	.0	.0	.0	.0	5.2
All species	13.4	9.0	3.6	1.3	.0	.4	.5	.0	.0	28.2
	SAMPLING ERROR[c]									
	Percent									
Red maple	30.0	36.4	49.7	71.2	.0	.0	.0	.0	.0	22.9
Sugar maple	53.1	.0	100.0	.0	.0	.0	.0	.0	.0	51.4
Yellow birch	48.1	100.0	100.0	.0	.0	.0	.0	.0	.0	44.3
Paper birch	36.9	47.9	50.7	100.0	.0	.0	.0	.0	.0	26.3
Beech	79.1	100.0	100.0	.0	.0	.0	.0	.0	.0	71.2
Ash[a]	51.5	.0	100.0	.0	.0	100.0	100.0	.0	.0	52.9
Aspen[b]	53.0	49.0	70.5	.0	.0	.0	.0	.0	.0	40.0
All species	20.3	24.2	25.5	58.1	.0	100.0	100.0	.0	.0	16.6

[a]Includes white and green ash.

[b]Includes quaking aspen and bigtooth aspen; does not include poplar species.

[c]Sampling error is a measure of the reliability of an estimate, and is expressed as a percentage of the estimate. The sampling errors given here correspond to one standard deviation, and are calculated as the square root of the variance, divided by the estimate, and multiplied by 100. An estimate that has an associated sampling error greater than 25 percent, but less than 50 percent should be used with caution; an estimate that has an associated sampling error greater than or equal to 50 percent is not significantly different from zero, and is unreliable.

Table 20.—Net growing-stock volume and sampling error of selected hardwood species suitable for turnstock on timberland by species and diameter class, Maine, 1982

Species	Diameter class (in inches)									All classes
	7.0–8.9	9.0–10.9	11.0–12.9	13.0–14.9	15.0–16.9	17.0–18.9	19.0–20.9	21.0–28.9	29.0+	
	GROWING-STOCK VOLUME									
	Million cubic feet									
Red maple	94.2	73.2	58.7	29.5	14.6	16.6	4.9	1.0	.0	292.7
Sugar maple	59.2	61.8	61.3	45.6	32.5	35.8	31.0	28.0	3.8	359.0
Yellow birch	37.7	47.3	34.1	29.4	30.6	13.5	11.4	19.4	.0	223.4
Paper birch	109.6	75.8	46.8	16.9	11.5	1.8	.0	.0	.0	262.4
Beech	19.1	15.2	29.5	10.2	8.8	3.2	.0	2.7	.0	88.7
Ash[a]	33.6	28.8	11.3	6.1	2.5	5.5	3.9	5.3	.0	97.0
Aspen[b]	95.6	98.5	77.3	45.9	16.8	8.4	5.9	1.3	.0	349.7
All species	449.0	400.6	319.0	183.6	117.3	84.8	57.1	57.7	3.8	1,672.9
	SAMPLING ERROR[c]									
	Percent									
Red maple	9.2	12.9	11.4	17.6	26.5	30.9	59.2	100.0	.0	7.7
Sugar maple	13.4	13.2	12.7	14.3	21.8	20.6	26.8	30.1	100.0	8.8
Yellow birch	14.0	16.6	13.7	15.5	19.3	32.7	38.7	39.1	.0	9.0
Paper birch	9.9	11.5	14.2	27.7	32.7	70.7	.0	.0	.0	8.0
Beech	27.6	23.5	17.5	29.5	35.8	60.6	.0	100.0	.0	13.5
Ash[a]	17.3	19.2	26.0	43.6	62.1	49.3	72.1	76.6	.0	16.7
Aspen[b]	15.1	14.7	11.9	16.5	31.0	38.9	57.8	100.0	.0	10.0
All species	5.7	6.1	5.7	7.8	11.0	12.9	18.9	21.6	100.0	4.2

[a]Includes white and green ash.

[b]Includes quaking aspen and bigtooth aspen; does not include poplar species.

[c]Sampling error is a measure of the reliability of an estimate, and is expressed as a percentage of the estimate. The sampling errors given here correspond to one standard deviation, and are calculated as the square root of the variance, divided by the estimate, and multiplied by 100. An estimate that has an associated sampling error greater than 25 percent, but less than 50 percent should be used with caution; an estimate that has an associated sampling error greater than or equal to 50 percent is not significantly different from zero, and is unreliable.

Wharton, Eric H.; Nevel, Robert L., Jr.; Powell, Douglas S. 1987. **Supply and demand of timber for wood turning in Maine.** NE–RP–599. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 29 p.

An analytical report on the volume of wood used by the wood-turning industry in Maine, and the volume of timber from the state's timberlands that may be suitable for turnstock. Findings are based on the third forest resource survey of Maine timberlands, and an industry canvass of primary manufacturing mills using wood from Maine timberlands, both conducted in 1982. Presents the volume of turnstock consumed by Maine mills, the volume produced from Maine timberlands, the volume suitable to be harvested for turnstock, and changes over time.

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Keywords: Forest survey, wood-turning industry, turnstock, consumption, production, supply, counties.

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Material Usage Trends in the Wood Household Furniture Industry

William G. Luppold

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Abstract

The wood household furniture industry is a major user of a variety of traditional and modern wood products. In the last two decades, traditional products such as hardwood lumber, veneer, and plywood have been replaced, in part, by modern composite products such as particleboard, hardboard, and medium-density fiberboard. We analyzed the uses of traditional and modern wood products by the wood household furniture industry and found that the substitution of composite products for traditional hardwood products has subsided in recent years.

The Author

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Introduction

The wood household furniture industry (SIC 2411) is the largest user of higher grade hardwood lumber and one of the largest users of hardwood veneer. Therefore, long-term lumber and veneer usage trends by this industry will affect long-term demand and price movements for these products and ultimately affect hardwood timber management decisions.

The usage of wood materials by the furniture industry has long been of interest to forest economists. USDA Forest Service scientists have periodically collected information on wood use in manufacturing (Gill 1965, Gill and Phelps 1969, McKeever and Martens 1983). Trends in wood usage by the furniture industry also have been analyzed by Forest Service scientists (Spelter et al. 1978). More recently, Cardellichio and Binkley (1984) have examined furniture usage of hardwood lumber in development of the Hardwood Assessment Market Model. Our study is more specific than past studies because we analyze material usage in the wood household furniture industry on an application-by-application basis in the furniture production process.

A serious problem associated with the analysis of material usage by the wood household furniture industry over time is the quality of data. Much of the data about this industry is incomplete and/or inconsistent over time. Recent U.S. Census data and Forest Service wood use in manufacturing data vary significantly. Therefore, we attempted to interpret the data in an easy-to-understand manner, fill in the data gaps, and account for some of the inconsistencies between data sources. A detailed discussion of the techniques used to arrive at the data in the figures and tables in this paper is in the appendices.

Solid Wood Products and Panel Products

Wood products used in furniture production can be divided into two groups—solid wood products and panel products. Solid wood products include hardwood lumber, softwood lumber, hardwood dimension, and wood furniture frames. Panel products include hardwood plywood, softwood plywood, particleboard, hardboard, medium-density fiberboard, and other products that are constructed of wood veneers, fibers, or particles. In this report, hardwood veneer is also considered a panel product even though it is normally produced and purchased in sliced flitch form in the domestic market.

Hardwood dimension is hardwood lumber that has been planed, worked, or shaped into a rough or finished furniture part or blank. Furniture frames are structural bases or members constructed primarily from wood. These intermediate materials are used because some furniture manufacturers want to purchase rough or finished furniture parts rather than process these parts from rough hardwood lumber. This usage of dimension may occur because the furniture manufacturer's rough-mill capacity is less than the capacity of the rest of his plant, or because the manufacturer does not have a rough mill. Because hardwood dimension and wood furniture frames used in wood furniture production are developed from lumber, the hardwood lumber used to produce these parts is categorized with lumber in this paper.

Veneer core and solid core hardwood plywood are two other products that a furniture manufacturer may produce in-house from veneer, particleboard, or lumber or purchase in finished form from an outside vendor. The use of panel products in furniture construction is not new. In fact, veneer and hardwood plywood usage in wood furniture construction existed in ancient Egypt. The change is the use of composite panel products constructed from wood fibers or particles such as particleboard, hardboard, or medium-density fiberboard. In recent years, composite wood products have increasingly substituted for hardwood lumber and plywood in several applications.

Recent Census statistics do not reveal the extent of substitution of nontraditional wood products for hardwood lumber, plywood, and veneer. In 1982, hardwood lumber was the most important material used by the wood furniture industry and accounted for 18 percent of the total material cost (Fig. 1). The second most important material on a dollar basis was hardwood dimension. Together, these two hardwood products, along with hardwood veneer and plywood and wood furniture frames, accounted for nearly 36 percent of the material cost in wood furniture production.

Even though hardwood material cost represents a major portion of the total material cost in wood furniture production, a large amount of softwood and composite materials has been substituted for traditional hardwood material over the last 30 years (Fig. 2). The three trend lines in Figure 2 indicate that: (1) the proportion of material cost for nonwood products such as glass, plastic, door hardware, paint, and varnishes remained nearly constant; (2) the proportion of material cost for other wood products such as softwood lumber, particleboard, fiberboard, and medium-density fiberboard increased by 300 percent between 1963 and 1972; and (3) the proportion of material cost for traditional hardwood materials such as hardwood lumber, veneer, and plywood decreased by nearly 30 percent. To better understand these trends, we examine the usage of solid and panel material in greater detail.

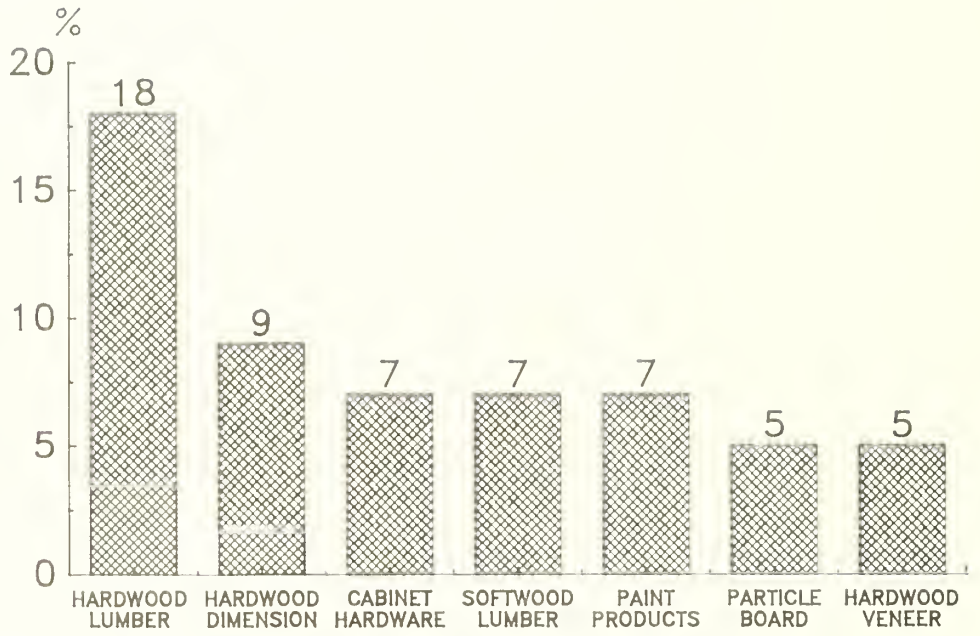

Figure 1.—Percentage of material cost for the seven predominant inputs in the wood household furniture product process.

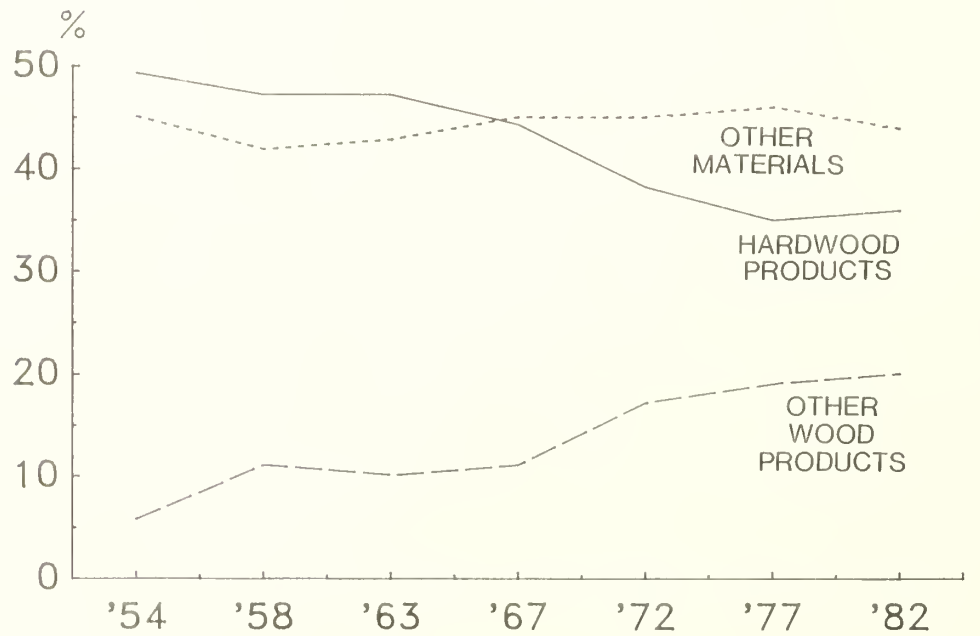

Figure 2.—Percentage of material cost for hardwood products, other wood products, and other materials, from 1954 to 1982.

Solid Material Consumption Trends

Solid wood material is used in furniture construction in four separate applications: (1) exterior solid parts, (2) interior parts, (3) core stock, and (4) banding material. Solid exterior parts are the solid boards, turning, or other parts that are visible when looking at a piece of wood furniture. Interior parts are the structural members, bracing, and drawer railing that are not usually seen when looking at a piece of furniture. One visible interior part is drawer slides, and these are visible when the drawer is pulled out. Core stock is lumber that is laminated with plywood veneer to form a veneered panel. Banding material is exterior lumber that is placed around the perimeter of a veneered panel.

Hardwood lumber still accounts for a large part of the total wood furniture material bill; however, Table 1 reveals some interesting trends. Total hardwood lumber usage increased by 19 percent from 1954 to 1982. However, hardwood lumber usage decreased by 7 percent between 1972 and 1982, while softwood lumber usage increased by 14 percent. It is more accurate to view quantity statistics after 1972 because before 1972 the kitchen cabinet industry was included as wood furniture. The inclusion of wood kitchen cabinets in 1967 and 1963 biased the lumber use statistics upwards; however, since fewer wood kitchen cabinets were manufactured in the early 1950's, the 1954 lumber use statistics are comparable to post-1972 statistics.

Table 1 also indicates continual increased usage of hardwood dimension by the wood furniture industry through the 1950's, 1960's and early 1970's. The large drop in hardwood dimension consumption indicated in 1977 resulted from the addition of rough-mill capacity by the furniture industry in anticipation of the baby-boom generation's demand for furniture. This increase in demand never materialized to expected levels, leaving the furniture industry with overcapacity. Since the dimension manufacturers have traditionally provided furniture manufacturers with the extra rough-mill capacity needed during peak production periods, the overcapacity in the furniture industry's rough end reduces the dimension industry's market.

The increase in dimension usage indicated in 1982 is seriously biased by the imports of unassembled furniture. This unassembled furniture is primarily chairs from Yugoslavia and occasional tables and dining room furniture from Taiwan. Because of unassembled furniture imports, the 1982 figures for dimension usage and lumber and dimension usage reported in Table 1 are not strictly comparable with previous years.

Table 1.—Estimated lumber consumed by the wood household furniture industry in the form of hardwood and softwood lumber and dimension stock and total amount of lumber, by Census year
(in million board feet)

Census year	Rough hardwood lumber	Softwood lumber	Dimension stock[a]	Total lumber	Total lumber and dimension[b]
1954	1,058	228	159	1,286	1,604
1958	1,112	258	180	1,369	1,729
1963	1,407	304	215	1,711	2,141
1967	1,333	307	295	1,640	2,230
1972	1,147	407	347	1,555	2,249
1977	1,251	495	274	1,746	2,294
1982	1,072	464	304	1,536	2,144

[a]Dimension stock includes wood household furniture frames.
[b]Includes rough material used to produce dimension.
NOTE: The information in this table has been estimated. For a detailed discussion of the estimation procedures used to generate these numbers, see Appendix 4.

Much of the decrease in hardwood lumber and total lumber usage between 1972 and 1982 can be attributed to the level of wood furniture production in these two periods. To better illustrate lumber usage over time by the furniture industry, hardwood lumber usage, total lumber usage, and furniture production are shown relative to one another since 1954 (Fig. 3). Since the base year is 1954, inconsistencies result from the inclusion of kitchen cabinet production. However, it is evident that the use of solid wood material by the furniture industry is decreasing over time. This figure indicates that alternative products had substituted for hardwood lumber prior to 1972, and since 1972 the use of hardwood lumber per piece of furniture seems to have increased slightly.

Figure 3 shows that softwood lumber usage has increased in recent years at the expense of hardwood lumber usage. Because the kitchen cabinet industry's statistics are included in the 1963 and 1967 observations, it is difficult to determine from the figure when this increase in usage occurred. However, it is still interesting to note that before 1972, softwood volume accounted for about 15 percent of the total wood use; while in 1972 and later, softwood volume accounted for about 20 percent of the total wood use. This increase probably resulted from the acceptance of character-marked material by furniture producers and consumers and the relatively low price of softwood lumber versus open-grained hardwood lumber, coupled with an increase in the popularity of Early American and rustic-styled furniture.

Panel Product Consumption Trends

Although hardwood lumber and dimension have been and are currently the major hardwood products used in wood furniture production, a tremendous amount of material substitution has taken place in the panel product market. Specifically, softwood panel products have substituted for hardwood plywood, lumber, and dimension.

In the early 1950's, thin veneer core hardwood plywood was used to construct drawer bottoms, dust bottoms, and furniture backs and sometimes was used to construct furniture sides. Lumber core hardwood plywood was used in the construction of visible furniture tops and sides and thus was an alternative to solid lumber. Softwood plywood at times was covered with a hardwood veneer to produce furniture tops. Since the 1950's, panel products application and variety have changed substantially.

Figure 4 shows the usage of the various panel products over time as a percentage of total dollars spent on materials. In 1954, more than 18 percent of the material cost of wood furniture was for hardwood plywood and veneer. By 1977, the proportion of the material dollar spent on hard-

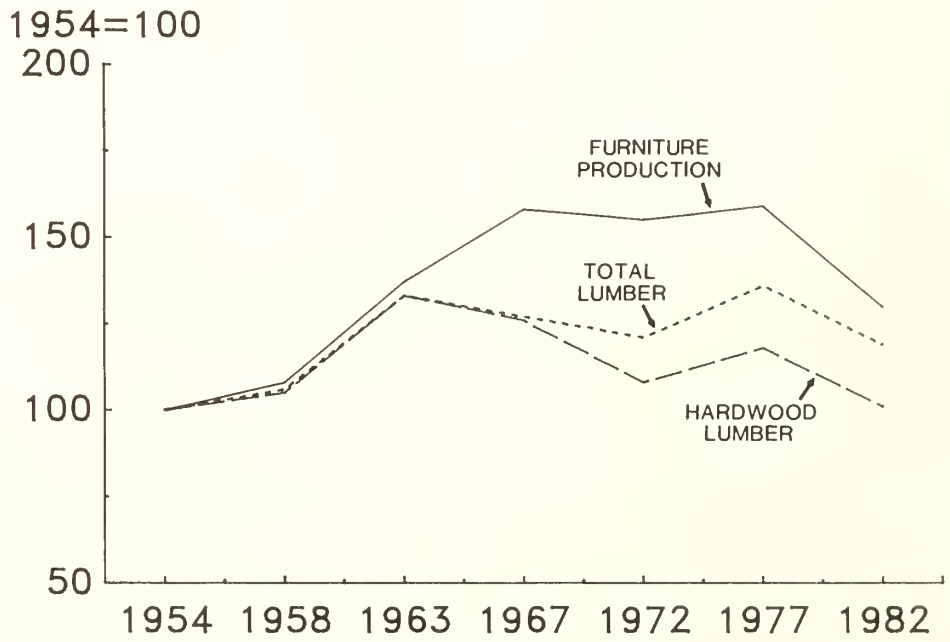

Figure 3.—Index of wood household furniture production, total lumber consumption, and hardwood lumber consumption, 1954 to 1982 (1954 = 100).

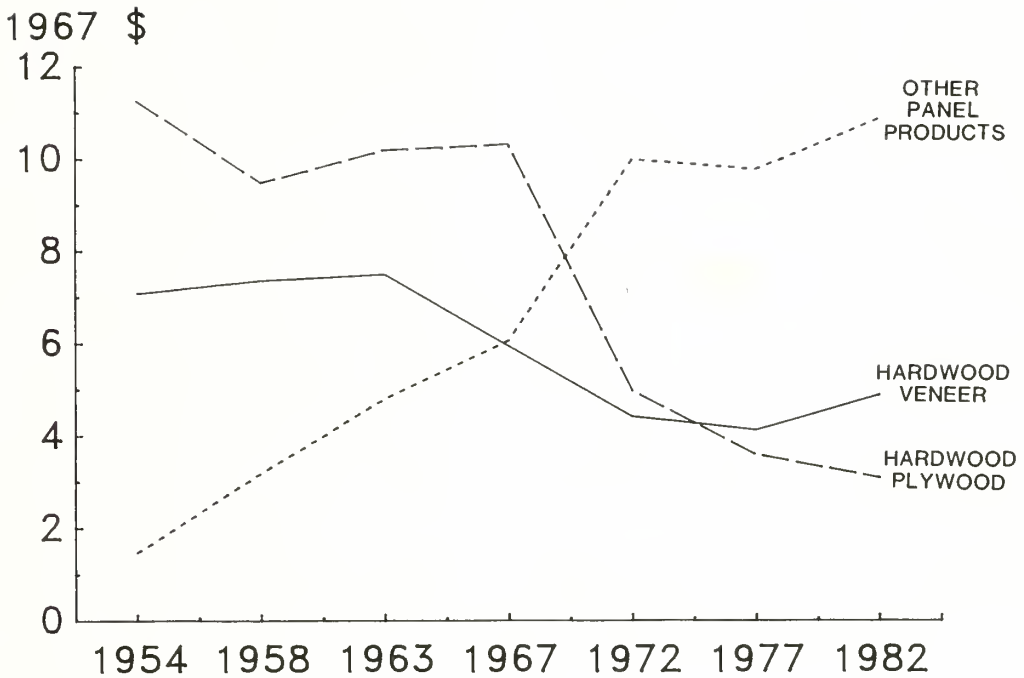

Figure 4.—Consumption of hardwood veneer, plywood, and other panel products over time (in 1967 constant dollars).

wood plywood and veneer was less than 8 percent. Although some of the decline in hardwood veneer and plywood used resulted from the use of thermo resins and other plastic products, the availability of less expensive composite panel products was the major reason for the decline.

Estimated usage of panel products by the wood furniture industry as reported by the USDA Forest Service and as derived from the Census of Manufacturers is shown in Table 2. The differences in these two data sources are apparent for the year 1977. This difference seems to emanate from the differences in product name versus physical specifications. Forest Service questionnaires list products by physical properties, while Census surveys ask for product by name. However, thin (1/8 inch) medium-density fiberboard is sometimes confused for thin hardboard because both these products are used for drawer bottom, dust bottom, and case-back applications. Some manufacturers also may term 3/4-inch medium-density fiberboard as 3/4-inch particleboard. However, when all composite board products are summed together on a 3/4-inch basis, the results of both surveys are similar.

As indicated in Table 2, the first major composite panel product used by the wood household furniture industry was particleboard. This product was used in place of hardwood lumber as core stock material in the production of furniture tops and sides. However, the use of particleboard as core material made usage of lumber banding material a necessary rather than optional part of solid core hardwood plywood construction. This necessity resulted from the fact that, unlike solid lumber core material that allowed for a smooth edge finish, particleboard only allowed for a rough-edge finish.

It is difficult to show the rate at which particleboard was substituted for lumber core stock over time because particleboard core and lumber core plywood are lumped together in Census data. However, the total impact of this substitution over time can be discussed. In 1954, 44 million square feet of lumber core hardwood plywood was used by the wood household furniture industry. If we assume a 70-percent yield of grade 2B poplar lumber into core stock material, approximately 63 million board feet of hardwood lumber was used to produce 44 million square feet of hardwood plywood. In 1982, 64 million board feet of solid core hardwood plywood was purchased by the wood household furniture industry, but the vast majority of this material was particleboard core. If we assume that 90 percent of the solid core hardwood plywood purchased in 1982 was particleboard core, the use of particleboard displaced 82 million feet of hardwood core stock in this

Table 2.—Panel usage by the wood household furniture industry for select years
(in million square feet)

Year	Particleboard (3/4" basis)	Hardboard (1/8" basis)	Medium-density fiberboard (3/4" basis)	Total composite board (3/4" basis)	Adjusted total composite board (1954 basis)
1958[a]	29	—	—	29	26.8
1960[b]	35	—	—	35	31.1
1963[a]	136	196	—	169	123.4
1965[c]	196	368	—	257	163.1
1967[a]	173	386	—	237	149.9
1972[a]	490	491	—	572	370.0
1977[a]	319	446	106	499	314.0
1977[d]	246	186	206	483	304.1
1982[a]	316	221	106	458	352.8

[a]Derived from Census of Manufactures.
[b]Reported by Gill (1968).
[c]Reported by Gill and Phelps (1969).
[d]Reported by McKeever and Martens (1983).
NOTE: All Census figures were estimated. See Appendix 4 for derivation.

Census year. In addition to particleboard purchased in solid core plywood form, at least another 420 million square feet of particleboard and medium-density fiberboard was purchased by the furniture industry. If we assume a 90-percent yield from board products and a 70-percent yield on lumber, each square foot of particleboard displaces 1.29 feet of rough lumber. Under this assumption, the total displacement of hardwood lumber by particleboard in 1982 was more than 620 million board feet.

The second composite product that displaced traditional hardwood products in furniture production was high-density fiberboard or hardboard. Unlike particleboard, which is an aggregate of wood particle held together by a resin, hardboard is composed of interlocking wood fiber formed with resins under pressure. The introduction of hardboard in the early 1960's and gradual acceptance of this product displaced thin veneer core hardwood plywood used in the production of drawer bottoms, dust bottoms, and chest backs in lower and middle-priced furniture. Drawer bottoms made of hardboard are many times covered with a thin vinyl cover that simulates the color and grain of oak. Today, thin plywood drawer bottoms and case backs are usually found only in the more expensive lines of furniture.

As shown in Table 2, hardboard usage by the furniture industry has decreased greatly since 1972. This decrease resulted from the adoption of a thin medium-density fiberboard, which has replaced hardboard in drawer bottoms and chest back application in lower priced furniture.

Medium-density fiberboard is constructed from wood fibers and is less dense than hardboard. The extent to which medium-density fiberboard has displaced hardboard is indicated in Table 2; however, medium-density fiberboard also has been used in place of solid wood, hardwood plywood, and particleboard. Because of its construction, medium-density fiberboard panels do not require edgebanding, and in painted furniture, no veneer. Since medium-density fiberboard was still being adopted after 1982, the impact of this product may be underestimated by the figures presented in this paper.

One other area where composite products have displaced hardwood lumber is in drawer-side production. Traditionally, hardwood drawer sides have been made of oak, sycamore, or other hardwood species. Although oak, sycamore, or mahogany drawer sides are still used in the production of more expensive furniture, less expensive furniture may have plywood or vinyl-wrapped particleboard or medium-density fiberboard drawer sides.

Material Substitution Over Time

The substitution of softwood lumber and composite panel product for hardwood lumber, veneer, and products constructed from hardwood lumber and veneer has occurred over several years. The actual extent of this substitution is difficult to determine because of changes in the level of furniture production. Therefore, the material usage indexes shown in Table 3 are adjusted for the level of furniture

Table 3.—Hardwood lumber, veneer core plywood, solid core plywood, veneer, softwood lumber, and composite board product usage indexes, adjusted for the level of furniture production, 1954 to 1982 (1963 = 100)

Year	Hardwood lumber	Veneer core plywood	Solid core plywood	Veneer	Softwood lumber	Composite panel products
1954	103	NA	82	95	103	NA
1958	100	133	75	105	108	22
1963	100	100	100	100	100	100
1967	85	NA	NA	70	91	122
1972	72	112	335	58	119	300
1977	77	85	129	40	141	255
1982	80	60	104	63	161	286

NA = not available.

production. All indexes are based on 1958 usage levels because that was the first year that Census data reported the use of composite panel products.

Three distinct growth periods in panel products usage are shown in Table 3. The growth in this index is tremendous because composite panels use grew from 1 percent of total material cost in 1958 to 12 percent of the total material cost in 1972. The first period was the late 1950's and was associated with the introduction of particle core stock material. The second period occurred in the 1960's with the introduction of hardboard and the continual growth in particleboard hardwood plywood. The third period occurred in the 1970's concurrently with print technology and consumers' acceptance of low-priced furniture containing very little traditional hardwood products. The second and third periods are where the greatest amount of material substitution occurred and need to be discussed in more detail.

The sharp jump in composite panel use between 1958 and 1963 corresponded to a drop in hardwood lumber, softwood lumber, veneer core plywood, and veneer usage. Three separate types of substitutions occurred at this point. The first substitution was particleboard for lumber as core stock material. The second substitution was particleboard core hardwood plywood for lumber in exterior part production. The third substitution was hardboard for veneer core plywood. Hardwood lumber usage dropped because less lumber core stock was used in-house, the use of hardwood lumber plywood increased, and less lumber was used for exterior applications. Veneer usage dropped because of less in-house production of veneer core plywood. However, face veneer usage probably increased because of increased usage of in-house production of particleboard core hardwood plywood.

The use of composite panel products reached its peak in the early 1970's as indicated by the 1972 indexes for hardwood plywood and composite panel products. This increase in panel product use is reflected by the decrease in hardwood lumber and veneer use. However, the decrease in hardwood lumber usage due to the substitution of softwood lumber accounted for nearly three-quarters of the 8 percent decrease in hardwood lumber usage between 1972 and 1977.

Between 1972 and 1982, hardwood lumber and veneer usage reversed historic trends and showed moderate increases against decreases in hardwood plywood and composite panel product usage. The decrease in veneer core plywood usage during this period indicates that there was substitution of composite products for veneer core hardwood plywood and, therefore, the substitution of lumber and veneer for panel products is understated by the composite products index. The increase in lumber and veneer usage has been attributed to the popularity of the rustic, historic look made popular by the U.S. bicentennial celebration and the rejection of the Mediterranean and printed furniture of the early 1970's.

Even though the current trend indicated in Table 3 shows an increase in the usage of traditional hardwood lumber and veneer, several other factors must be considered. First, 1982 was an unusual year in furniture demand because the recession affected lower priced furniture more than higher priced furniture. Since higher priced furniture tends to be constructed from more traditional materials, there is an upward bias for hardwood lumber and veneer usage in Table 3. Second, the more wood-intensive rustic look of the mid-1970's is in part being replaced by the less wood-intensive modern look of the mid-1980's.

Conclusion

The availability and adoption of composite panel products have resulted in much of the lower priced furniture containing none of the traditional hardwood products. The opposite extreme is high-priced furniture, which is still produced from hardwood and veneer. In the future, the less expensive furniture will most likely continue to be produced from composite panel products and plastics, while very expensive furniture will be produced using traditional material. The medium-priced furniture market, however, is where the interchange of new and traditional wood-based and nonwood-based material will occur in the future. The word interchange is used instead of substitute because future demand and supply conditions may merit more or less use of traditional hardwood materials rather than continual substitution away from these materials.

Future levels of wood material uses by the wood household furniture industry will depend on the level of furniture demand, the quality of furniture purchased, the quantity of furniture that is imported from other countries, the production technique used to produce furniture, furniture styling, and the physical dimension and size of furniture. If current trends persist, though, hardwood lumber usage may decrease if only because of increases in imports of rough or finished dimension. Hardwood veneer use could increase if veneer-wrapped medium-density fiberboard replaced hardwood lumber in applications where hardwood molding was previously used. No matter what happens in furniture production techniques, however, domestic furniture producers will have to become more cost conscious to stem the tide of furniture imports that have persisted since the early 1980's.

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Appendix 1

Accounting for Material Not Specified by Kind (nsk)

There are two aggregate categories in the Census of Manufacturers:

(1) All other material and component parts, containers, and supplies
(2) Material, parts, containers, and supplies (nsk)

The first category includes materials that were not specifically listed on the questionnaire. The second category includes materials used by establishments that did not report detailed material use data. This second category is of interest since it includes materials that are also listed by kind. Thus, the figures for material listed by kind are underestimates. To account for these underestimates, all value and quantity figures used in this paper have been adjusted using the following formula:

$$\frac{0}{1 - \text{pnsk}}$$

where:

0 = original value of figure being adjusted
pnsk = percentage of total material usage classified in the nsk category

Appendix 2

Development of Figures

Figure 1. Proportions shown were derived by dividing material cost for specific item by total material cost less material cost in nsk category.

Figure 2. Proportions shown were derived by dividing material cost for specific groups of items by total material cost less material cost in nsk category. Hardwood products group is composed of hardwood lumber, veneer, plywood, dimension, and furniture frames. Other wood products group is composed of softwood plywood, particleboard, hardboard, medium-density fiberboard, and softwood lumber. Other materials group is composed of all other materials not included in the first two groups.

Figure 3. Wood household furniture production index was developed by dividing value of shipments by price index for furniture, then indexed with 1954 = 100. Hardwood lumber usage index was developed by indexing hardwood lumber usage information presented in Table 1. Total lumber usage index was developed by indexing total lumber usage information presented in Table 1.

Figure 4. Dollars spent on hardwood veneer, hardwood plywood, and other panel products were adjusted upward for Census-reported figure to account for percentage of material in nsk category. Other panel products include softwood plywood, hardboard, particleboard, and medium-density fiberboard.

Appendix 3

Development of Missing Quantity Information

Quantity figures were suppressed for several wood products, especially in recent Census years. These omitted figures were estimated using the formula:

$$Q = (V/PI)s$$

where:

Q = the quantity of the commodity

V = the value of the commodity as reported in the Census of Manufactures

PI = the price index for the commodity

s = a scaler calculated from quantity, value, and price index data for the Census year closest to the missing observation. The formula for s is:

$$s = PI_c\,(Q_c/V_c)$$

where:

PI_c = the price index for the commodity in a Census year closest to the missing observation

Q_c = the quantity of the commodity in a Census year closest to the missing observation

V_c = the value of the commodity in a Census year closest to the missing observation

Appendix 4

Development of Information Reported in Tables

Table 1. Rough hardwood lumber usage adjusted upward to account for nsk category (Appendix 1). The 1982 figure was estimated using formula outlined in Appendix 3. Softwood lumber usage was adjusted upward to account for nsk category (Appendix 1). Dimension stock usage was figured on dimension and frames. The price used to estimate board-foot quantity of frames was the imputed price for dimension. Quantities were adjusted upward to account for nsk category (Appendix 1). The 1977 and 1982 figures were estimated using formula outlined in Appendix 3. Total lumber usage figure was calculated by adding total hardwood lumber usage figures to softwood lumber usage figures. Total lumber and dimension usage figure was calculated by adding lumber usage with 2 times dimension stock usage. This assumes a 50-percent yield from lumber to dimension.

Table 2. Particleboard usage figures were derived from Census information and adjusted upward to account for nsk category (Appendix 1). The 1958 figures were converted from 3/8-inch basis to 3/4-inch basis. The 1977 and 1982 figures were estimated using the formula outlined in Appendix 3. Hardboard usage figures were derived from Census information and adjusted upward to account for nsk category (Appendix 1). The 1967, 1977, and 1982 figures were estimated using the formula outlined in Appendix 3. Medium-density usage figures derived from Census information were adjusted upward to account for nsk category (Appendix 1). The 1977 figure was estimated using formula outlined in Appendix 3. Total composite board usage was derived by adjusting all data to a 3/4-inch basis and summing.

Table 3. Hardwood lumber usage index was based on information presented in Table 1. Veneer core plywood usage index was based on raw data adjusted upward to account for nsk category (Appendix 1). The 1982 raw veneer usage data was estimated using formula outlined in Appendix 3. Solid core plywood usage index was based on raw data adjusted upward to account for nsk category. The 1977 and 1972 raw veneer usage data was estimated using formula outlined in Appendix 3. Softwood lumber usage index was based on information presented in Table 1. Composite panel product index was based on information presented in Table 2.

Luppold, William G. 1987. **Material usage trends in the wood household furniture industry.** NE–RP–600. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 10 p.

Examines wood material usage by the wood furniture industry in descriptive and numerical terms.

ODC 721.1

Keywords: Hardwood, lumber, composite products

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Experiment Station**

NE-RP-601

Hardwood Lumber and Stumpage Prices in Two Eastern Hardwood Markets: The Real Story

Neal P. Kingsley
Paul S. DeBald

Abstract

Hardwood lumber and stumpage prices appear to have risen substantially between 1964 and 1985. However, deflating these prices shows that inflation wiped out these increases for most species in two hardwood lumber markets and in a stumpage market. Only red oak, ash, and black cherry lumber prices increased faster than the rate of inflation. Yellow-poplar, basswood, hard maple, and soft maple prices actually declined in real terms.

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Introduction

To the casual observer, hardwood lumber and stumpage prices would seem to have increased significantly during the past two decades. Market prices for hardwoods have nearly tripled between 1964 and 1985. The increases in hardwood prices were, of course, part of an overall inflationary spiral that began in the early 70's and subsided only recently.

However, hardwood prices did not increase consistently from one species to another, nor from one area to another. Because of declines in demand and changes in hardwood markets, the increases in the market price of many hardwood species failed to keep pace with the overall rate of inflation. Thus, the real or deflated prices for many species have actually dropped during the past two decades.

In this paper, we will explore the price trends—market and real—for eight important eastern hardwood species in the Appalachian and Northern hardwood lumber markets.

The Price Deflators

A period of inflation is defined as a time of generally rising prices for commodities and the factors of production (Samuelson 1964); or, stated in monetary terms, a period when the value of money is decreasing. Thus, more and more money is required to purchase the same goods. For example, in 1964, 1,000 board feet (Mbf), of #1 common 4/4 Appalachian white oak sold for $110 f.o.b. the mill. In 1985, the same lumber sold for $362 per Mbf, an increase of 229 percent. How much of this increase was due to an increase in demand or a decrease in the supply of white oak, and how much of this apparent change was due to the decrease in the value of money?

To answer these questions economists use a price index. A price index compares the current price of a good or service with its price in a predetermined base year. The base year 1967 is used commonly. Using a price index, we can deflate current reported prices in various years to comparable 1967 prices. Various price indices are suited to measuring various segments of the economy. The most familiar is the Consumer Price Index or CPI. This measures the price of a hypothetical aggregation of typical consumer goods and services at any given time relative to the price of the same goods and services at a particular point in time. Thus, according to the CPI, $319 was needed in 1985 to purchase the same goods that $100 purchased in 1967. Or, 31.9 cents in 1985 has the same purchasing power as $1.00 in 1967.

Hardwood lumber has no utility in and of itself until it is used to produce a final product—a chair, a pallet, or part of a home. Hence, it is termed a producer good as opposed to a consumer good. By using a Producer Price Index or PPI, we can get a more accurate measure of the relative price of hardwood because it does not include the costs of consumer goods and services. The most commonly used PPI is the "Producer Price Index of All Commodities," formerly called the "Wholesale Price Index." This index includes nearly 3,400 commodities selected to represent the movement of prices of all commodities produced in the manufacturing, agriculture, forestry, fishing, mining, gas and electricity, and public utilities sectors of the economy.

Producer Price Indices also can be developed for various commodities or stages of production. The appropriate index for our purposes is the "Hardwood Lumber Producer Price Index" or PPI-Hardwood. By using this index, we can look at the relative prices in transactions involving only the production of hardwood lumber.

All three price indices, CPI, PPI, and PPI-Hardwood, are shown in Figure 1. Of the three, PPI-Hardwood shows the greatest change from quarter to quarter because it is restricted to a single commodity—hardwood lumber. The curve is not smoothed out by off-setting changes in prices of different commodities. For this reason, PPI-Hardwood most accurately reflects the relative prices of hardwood lumber. Because the PPI-Hardwood applies to the general price level of all hardwood lumber produced in the Nation, we can expect some variation from one region to another, from one species to another, and from one lumber grade to another.

Hardwood Lumber Price Trends

By applying the Hardwood Lumber Producer Price Index to hardwood lumber prices, we can convert current prices to their relative 1967 price. These prices relative to 1967 are called "real" prices. The current prices used in this paper are those reported in "The Hardwood Market Report" for two hardwood lumber market areas: the Appalachian market centered in Johnson City, Tennessee, and the Northern market centered in Wausau, Wisconsin.[1] Prices reported are average market prices for carload quantities f.o.b. the mill.

Our discussion is limited to eight major eastern hardwood species: black cherry, basswood, ash, red oak, white oak, soft maple, hard maple, and yellow-poplar. Black cherry, white oak, and yellow-poplar are not traded in sufficient quantities in the Northern market to provide reliable price quotations. Thus, regional price comparisons are not possible for these species. The remaining five species are traded in both markets. Graphs of the current and real lumber and stumpage prices of these eight species are in the Appendix.

[1] Hardwood Market Report, P.O. Box 40042, 1418 Madison Ave., Memphis, TN 38174-0042.

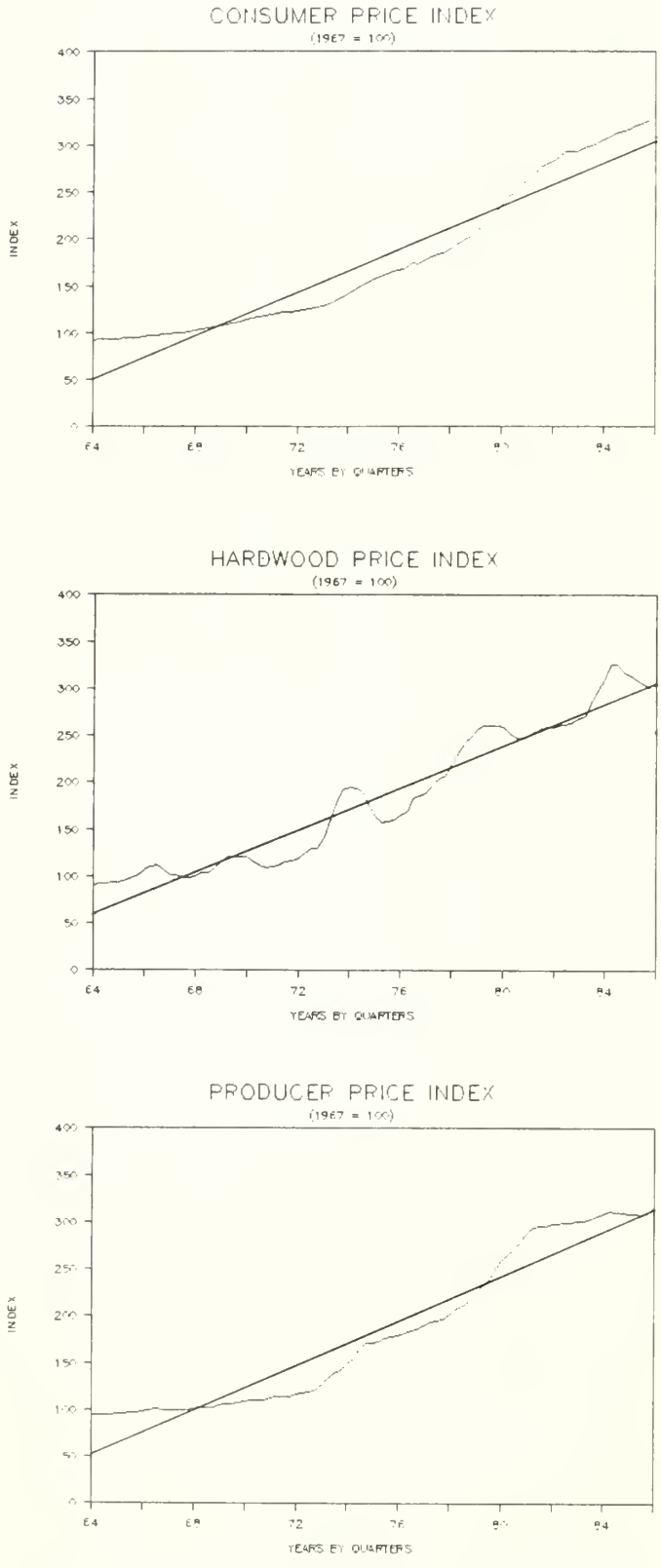

Figure 1.—Three price indices—1967 = 100—1964–1985.

Table 1 shows the real and current prices of No. 1 common lumber at the opening and closing of the 21-year period. The table shows that the real price of No. 1 common white oak lumber was less than 1 percent below what it was in 1964—in other words, it remained essentially unchanged. Real prices of many of the above species failed to keep pace with inflation. Some, in fact, fared quite poorly. Soft maple in the Northern market closed the 21-year period with a real price drop of 48 percent. Only three species were able to stay ahead of inflation. These were red oak in both markets, and ash and black cherry in the Appalachian market.

Lumber prices generally followed economy-wide price trends during the period. From 1964 through 1973, inflation averaged 4.4 percent per year. During this period, current lumber prices remained steady or rose modestly. For the period 1973 to 1980 the rate of inflation averaged about 9.4 percent and current lumber prices rose sharply. Lumber prices became erratic during this period as producers struggled to cover skyrocketing production costs and consumers resisted sharp price increases. Some species successfully resisted sharp increases in current price. This is more clearly evident for those species with a normally low demand, such as yellow-poplar and the maples. These are the "losers" and "big losers" in Table 1. By 1980, inflation had peaked at 14 percent and it seems that every species resisted the tendency to increase in price. Inflation began to moderate in 1981 and 1982. Generally, the higher valued species continued to increase in current price while the lower valued species tended to stay on or near the same plateau. By 1983, inflation had subsided to about 2 percent, and current prices of many species began to show signs of declining. Although it may be too early to tell, this may indicate a return to moderation in current price trends in the hardwood lumber industry.

Factors That Influence Hardwood Price Trends

The price of any commodity is ultimately a function of supply and demand. For lumber, price is determined by the supply of lumber made available by sawmills, called millstocks, and the demand of hardwood lumber consumers for these millstocks. The overall demand for hardwood lumber, as measured by production, has been declining in recent years. Hardwood lumber production in the United States declined from 7.2 billion board feet in 1952 to 6.7 billion in 1977 (USDA Forest Service 1982). The significance of this decline is amplified by the fact that the population in the United States rose from 157.6 million in 1952 to 216.9 million in 1977 (USDA Forest Service 1982). Thus, on a per-capita basis domestic hardwood lumber production fell from 45.7 to 30.9 board feet. Most of this decline has been brought on by favorably priced substitutes for hardwoods in many products, primarily steel and plastics. Because the demand for hardwood lumber has not grown, the real price of hardwood lumber generally cannot grow.

Table 1.—Real and nominal prices of No. 1 Common 4/4 lumber per thousand board feet, f.o.b. the mill, for select species by price trend[a] in two regional markets, 1st quarter 1964 and 4th quarter 1985

Species	Market[b]	Real price (1967 dollars)				Current price (Current dollars)			
		1964	1985	Price change	Price change	1964	1985	Price change	Price change
				Dollars	*Percent*			*Dollars*	*Percent*
				WINNERS					
Red Oak	AH	125	146	21	17	115	450	335	291
Ash	AH	134	147	13	10	124	452	328	264
Red oak	NH	146	152	6	4	135	467	332	246
Black Cherry	AH	195	198	3	1	180	608	428	238
				MODERATE LOSERS					
White Oak	AH	119	118	-1	-1	110	362	252	229
Ash	NH	163	153	-10	-6	150	470	320	213
				LOSERS					
Basswood	AH	148	101	-47	-32	137	310	173	126
Hard Maple	AH	168	108	-60	-36	155	332	177	114
Soft Maple	AH	173	109	-64	-37	160	335	175	109
				BIG LOSERS					
Yellow-poplar	AH	147	88	-59	-40	136	270	134	98
Basswood	NH	146	88	-58	-40	135	270	135	100
Hard Maple	NH	163	91	-72	-44	150	280	130	87
Soft Maple	NH	168	87	-81	-48	155	267	112	72

[a]Winners—Real price remained the same or increased.
Moderate Losers—Real prices declined less than 10 percent.
Losers—Real prices declined 10 to 39 percent.
Big Losers—Real prices declined 40 percent or more.
[b]AH—Appalachian hardwood market, Johnson City, TN, and vicinity.
NH—Northern hardwood market, Wausau, WI, and vicinity.

This explains the overall trend in hardwood lumber, but what about the short-run ups and downs? Again the answer is supply and demand, but, in this case, short- run supply and demand. The hardwood lumber market is cyclical. This cycle depends both on the normal business cycle and on seasonal variation in production. Over 50 percent of all hardwood lumber goes into industrial uses.[2] Therefore, hardwood lumber demand is strongly influenced by general industrial activity. As industrial activity improves, inventories at sawmills, called millstocks, are drawn down. As millstocks decrease, lumber price increases. This price increase stimulates production which builds millstocks until supply again exceeds demand and price beings to decline (Luppold 1986). This inherent cyclical tendency is accelerated by the large number of very small, part-time mills in the industry. As prices increase, these mills go into production to replenish millstocks rapidly. As prices drop, these mills go out of production. This tends to make the distance between peaks and valleys in production much steeper. Hardwood lumber prices are influenced by the business cycle. This is shown by comparing the short-run movement of prices with the overall economy. It is more evident when looking at real price changes than when looking at the movement of current prices. Inflation has the effect of masking the true movement of prices.

Hardwood lumber prices are also influenced by seasonal production cycles. In many regions, winter weather forces a slowdown in logging activity. Also, many areas limit gross vehicle weight on secondary roads in the spring to reduce road damage. This means that logs cannot be hauled to the mill during these times. If millstocks are low going into these periods, prices can be expected to continue to rise because millstocks cannot be easily replenished. Conversely, during periods of good weather millstocks may increase in anticipation of poor weather to the point that prices may become depressed.

We have discussed the reasons for long- and short-run price movements, but why did some species and grades do better than others during the past two decades? Hardwood lumber is used in a vast array of products from fine furniture to shipping pallets. Demand for quality uses such as furniture depends greatly on consumer preference. Over the past two decades, oak furniture has been preferred. Maple furniture, on the other hand has lost favor with consumers. Black cherry has maintained favor, and, since supplies of furniture grade cherry are limited, prices have increased. In addition to being a preferred species for furniture in the U.S. market, exports of oak have increased significantly since 1972 (Luppold and Jacobsen 1985).

Export demand for oak primarily effects the best grades called Firsts and Seconds (FAS). However, domestic demanders of FAS, to some degree, can shift demand to the next lower grade, No. 1 Common (1C) (Luppold and Jacobsen 1985). This has tended to increase the price of 1C oak lumber.

Other species have few outlets to speak of relative to their abundant supply. Consumption of soft maple and yellow-poplar lumber has declined while timber inventories of these species have increased.

Lumber Prices and Stumpage Prices

The stumpage prices quoted here are from "Ohio Timber Prices" published semiannually by the Ohio Crop Reporting Service of the USDA Statistical Reporting Service. Five other states in the northeast—Maine, Massachusetts, New York, Pennsylvania, and West Virginia—publish stumpage prices either semiannually or bimonthly. Two others, Kentucky and New Hampshire, publish annual price reports (Rosen 1984). Ohio prices were used here because they are believed to be generally representative of prices in the hardwood region and because they provide comparable information for the period 1964 through 1985.

As a general rule, real stumpage prices in Ohio have followed the same trends as real lumber prices in the Appalachian market area. Two exceptions are black cherry and soft maple. Despite the fact that real prices of black cherry lumber have increased in the Appalachian market, black cherry stumpage prices have declined in Ohio. The reason for this is that black cherry is not a commercially important species in Ohio (Dennis and Birch 1981). The black cherry sawtimber in Ohio is of too poor quality for furniture stock—76 percent is in Grade 3 or poorer sawlogs. Soft maple stumpage prices, while declining, have not declined as rapidly in Ohio as have soft maple lumber prices in the two market areas. An explanation for this may be Ohio's relatively large pallet industry, which can utilize soft maple along with many other species. Thus, a stronger demand for soft maple seems to exist in Ohio than in other states in the region.

Stumpage prices are residual prices. They represent the difference between the selling price of lumber and the total operating costs and profits incurred in removing the timber and converting it into lumber (Zaremba 1963). The actual cost of growing the timber is, therefore, not reflected in the stumpage price. The would-be timber seller, of course, must be aware of what it costs to grow timber. For only by knowing these costs can the seller know what price will recover the cost of growing timber.

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[2] Personal communication with W. G. Luppold, Northeastern Forest Experiment Station, Princeton, WV.

Because stumpage prices are derived from lumber prices, lumber prices exert a push-pull effect on stumpage prices. Rising lumber prices tend to pull stumpage prices up and, conversely, falling lumber prices tend to depress stumpage prices (Zaremba 1963). However, lumber and stumpage do not move together. Since lumber prices must increase in order for stumpage prices to increase, there is a lag in the increase in stumpage prices.

The short-run trends of real stumpage prices clearly show the effect of the oil crises of 1973 and the mid to late 1970's. This reflects the fact that motor fuel is a significant cost item in modern logging. In order to cover this increased cost, loggers were forced to bid lower for stumpage. This situation did not correct itself until inflation began to moderate about 1980.

The Potential Timber Seller and the Timber Market

The owner of nonindustrial private forest land who is contemplating the sale of timber needs to understand both the hardwood lumber and stumpage markets in the selling area. Most particularly, one needs to be aware of how inflation can mask the real changes in lumber and stumpage prices. As we have seen, substantial increases in price can be more than cancelled out by inflation. By observing the actions of the lumber market, the seller can anticipate increasing or decreasing stumpage prices. By keeping an eye on the general business cycle, the potential timber seller can get a feel for trends in hardwood lumber and stumpage prices. Millstocks and weather patterns are also important barometers of short-run price trends. It is important for potential sellers to remember that increases in lumber prices often foretell a rise in stumpage prices. Keeping an eye on trends in the lumber or stumpage markets is easier said than done. Public reporting of lumber or stumpage prices on a regular basis is not available in most areas. For this reason it is in an owner's best interest to obtain the services of a forester to handle the timber sale. Most foresters are familiar with the timber market in their area and are in a position to predict upswings and thus recommend the best time for an owner to offer timber.

As we have seen, the real lumber prices of most hardwood species have declined in the Appalachian and Northern market areas since 1964. So have real stumpage prices for most of these species in Ohio. We have also noted that stumpage prices do not reflect the actual costs of growing timber. In the face of long term declining real stumpage prices, it will often be difficult for the timber grower to justify expenses incurred in cultural treatments solely on the basis of future stumpage values. When considering treatments, the owner, therefore, should favor thinnings and other treatments that can pay for themselves in terms of saleable products or those treatments that improve the non-commodity values of his woodland.

The potential timber seller should also keep in mind that large, top-quality logs will bring a substantially better price than smaller logs of lower quality. Figure 2 illustrates this fact. Notice that delivered prices of Grade 1 sawlogs over 16 inches diameter at the small end, inside bark averaged 28 to 65 percent above the average price of all logs delivered to Ohio mills in the September through November 1985 reporting period. Conversely, prices of Grade 2 and 3 logs ran as much as 60 percent below the average. Thus, the timber grower would do well to identify those potentially large high-value trees early and to favor their growth and development into money-making trees. Past performance indicates that black cherry, red oak, ash, and white oak would be the species to favor (Table 1). On the other hand, the maples and yellow-poplar should generally be discouraged.

This study is based on past market performance of selected hardwood species in two lumber markets in the Eastern region of the United States. The reader should keep in mind that the situation may be significantly different in other regions and for other species. In addition, unforeseen developments, such as changing consumer preferences or improved utilization may significantly improve the marketability of presently low-value species. Thus, however unlikely it may seem at this point in time, it may not be safe to assume that "the past is prologue."

Also this analysis covers a broad region and local situations may vary significantly from the broader regional picture. For this reason, potential timber sellers need to be aware of the local market situation as well as the larger regional picture. For instance, a strong market for yellow-poplar or other generally lower value species may exist locally while the market for ash is very poor.

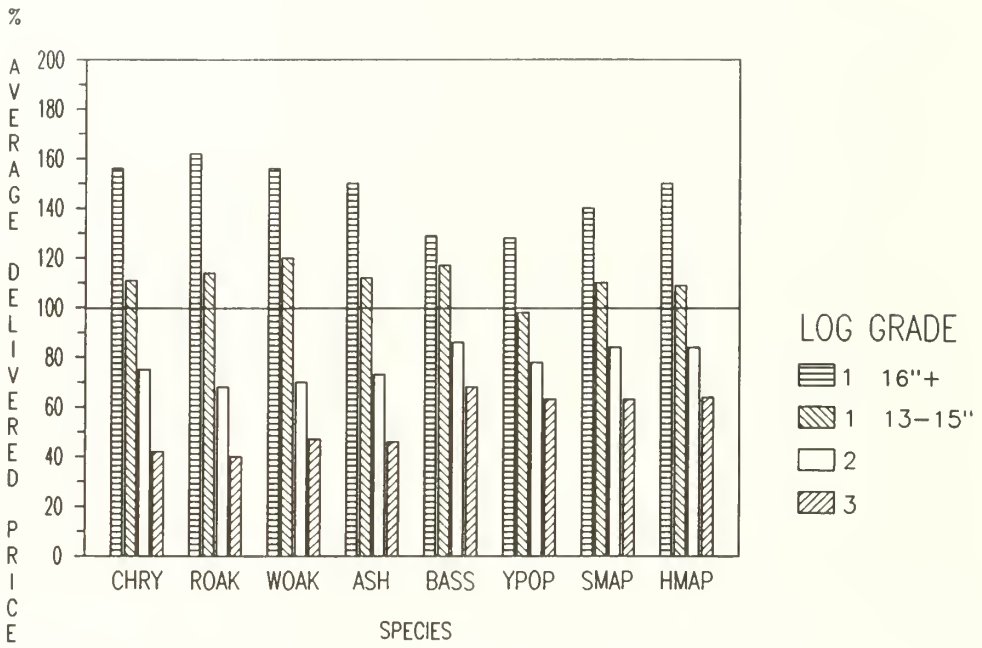

Figure 2.—Delivered log prices by species and log grade compared to average prices of all delivered logs by species, Ohio, September-November 1985.

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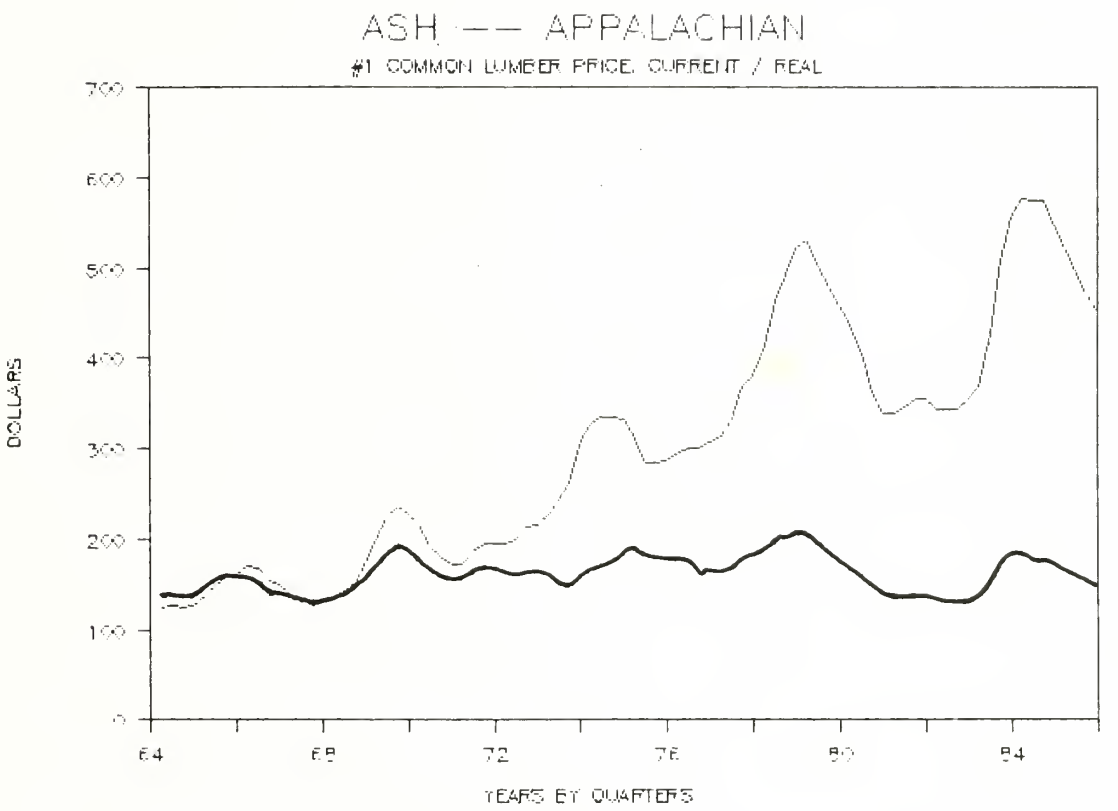
Appendix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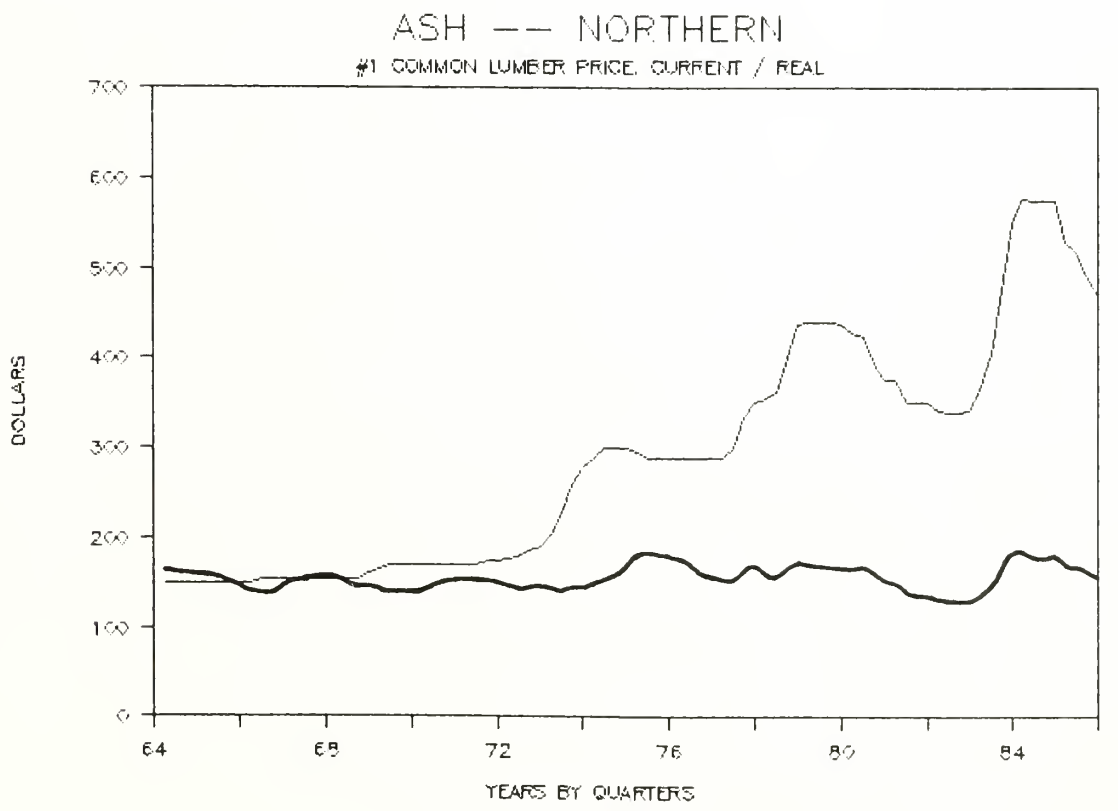
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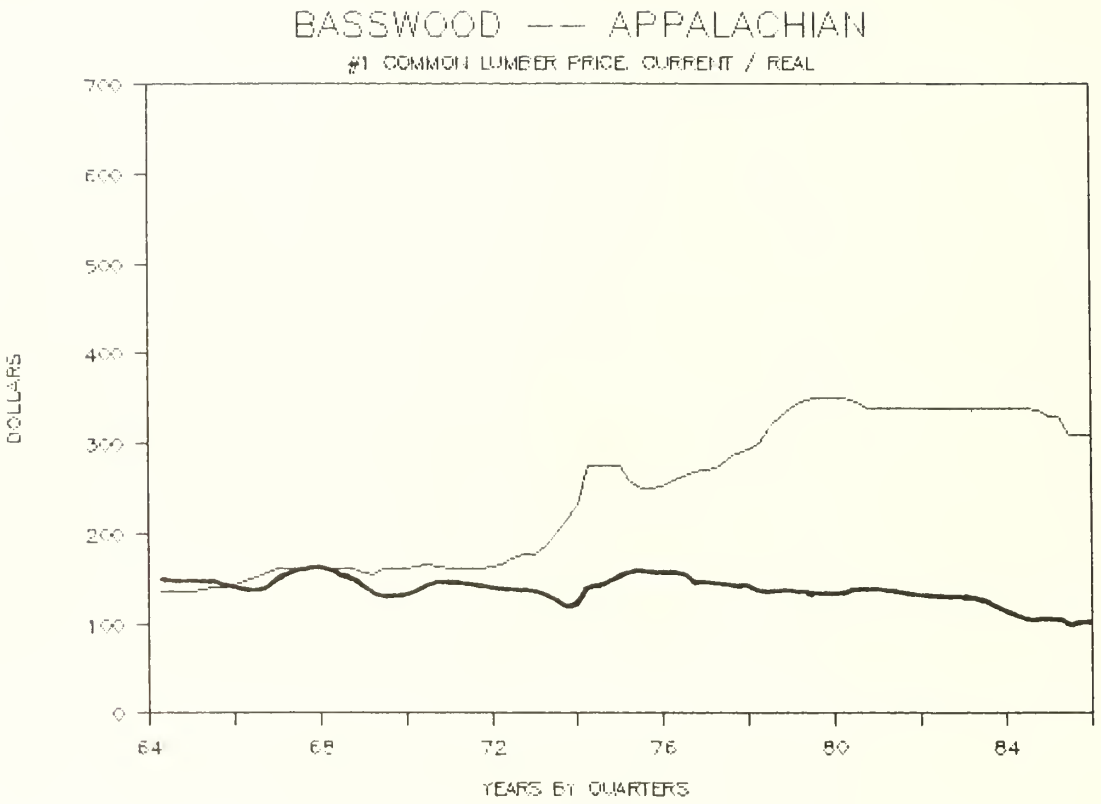
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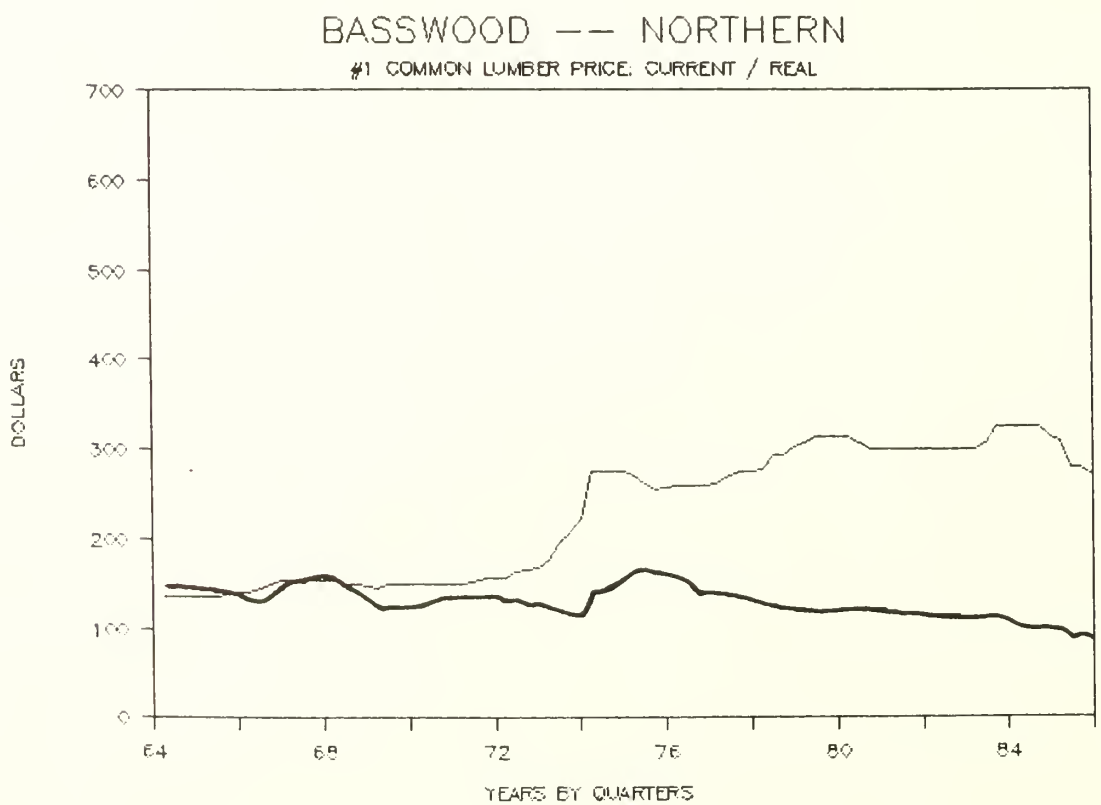
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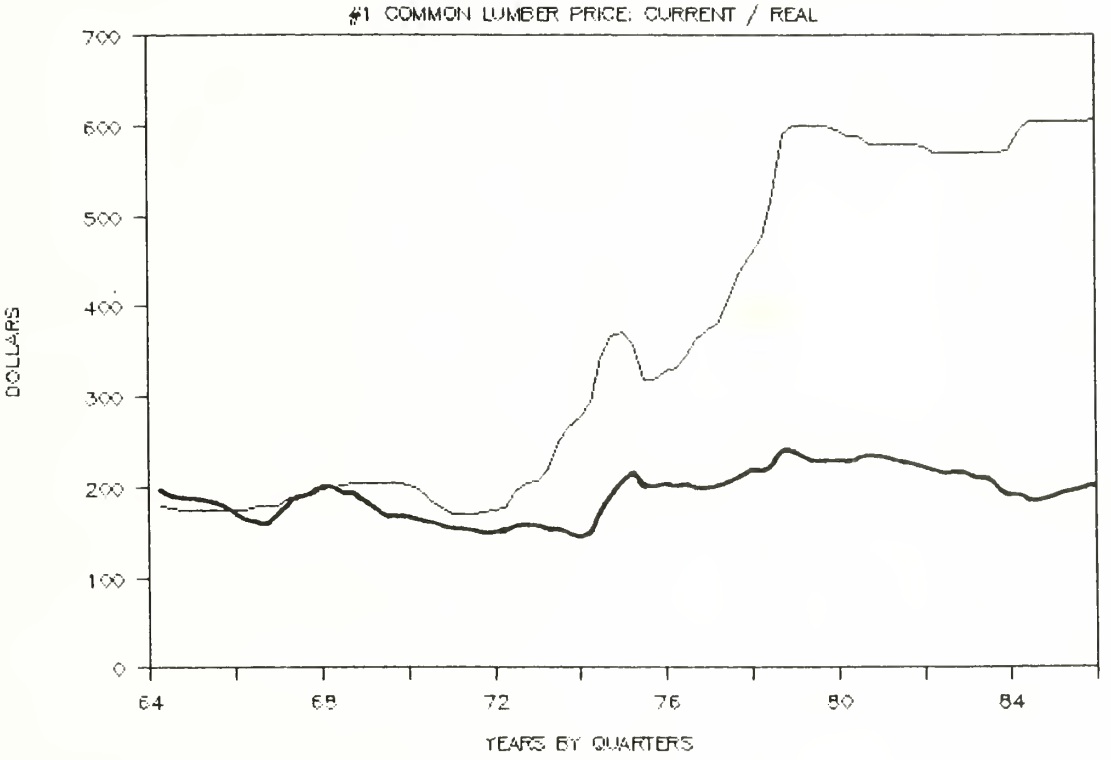
YEARS BY QUARTERS

BLACK CHERRY -- APPALACHIAN

#1 COMMON LUMBER PRICE: CURRENT / REAL



HARD MAPLE -- APPALACHIAN

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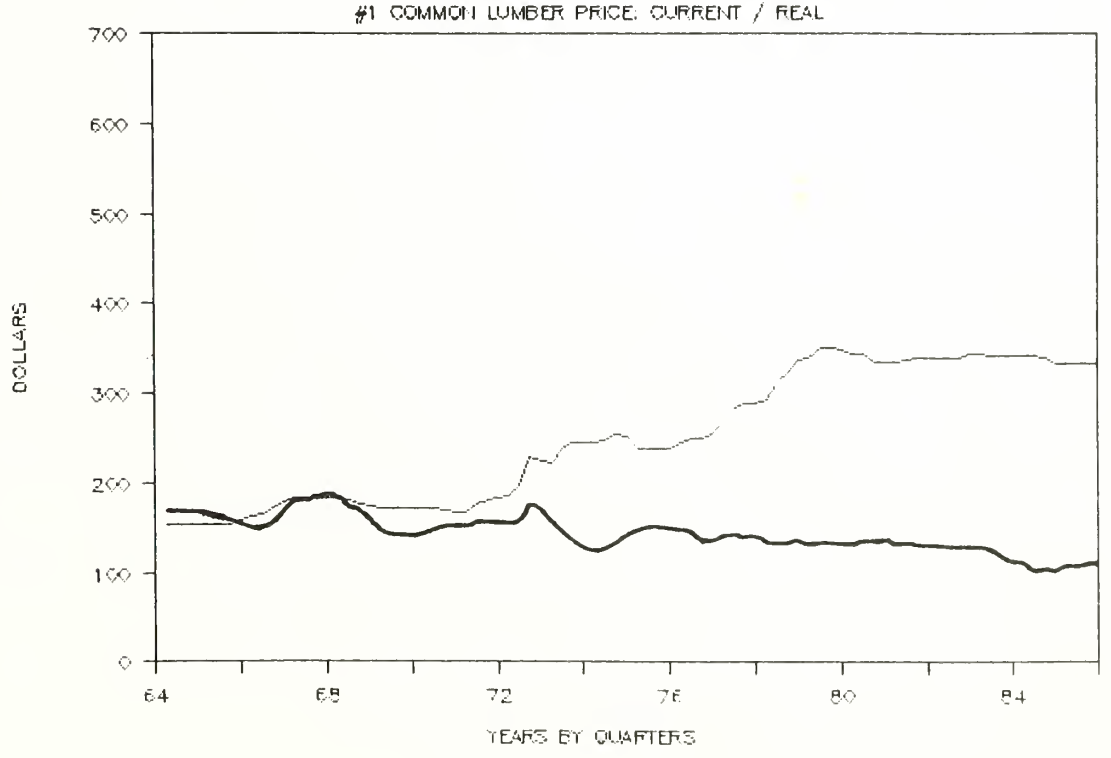

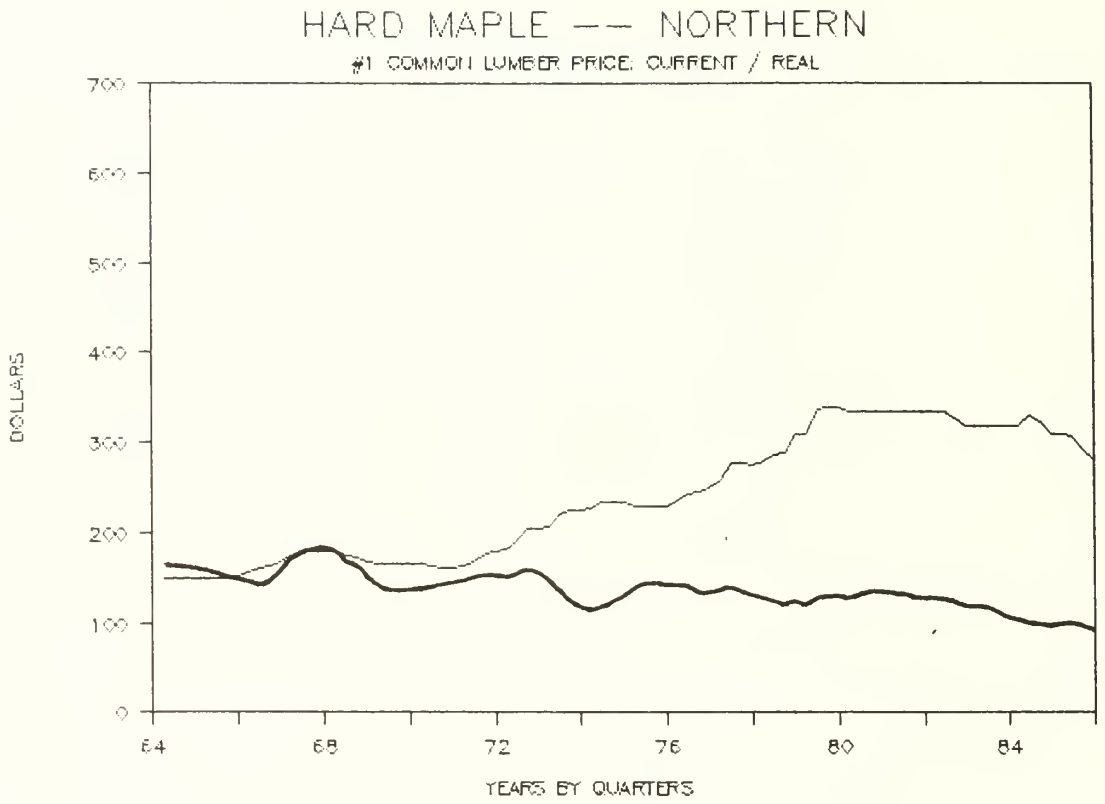
HARD MAPLE -- NORTHERN
#1 COMMON LUMBER PRICE: CURRENT / REAL
DOLLARS
700
600
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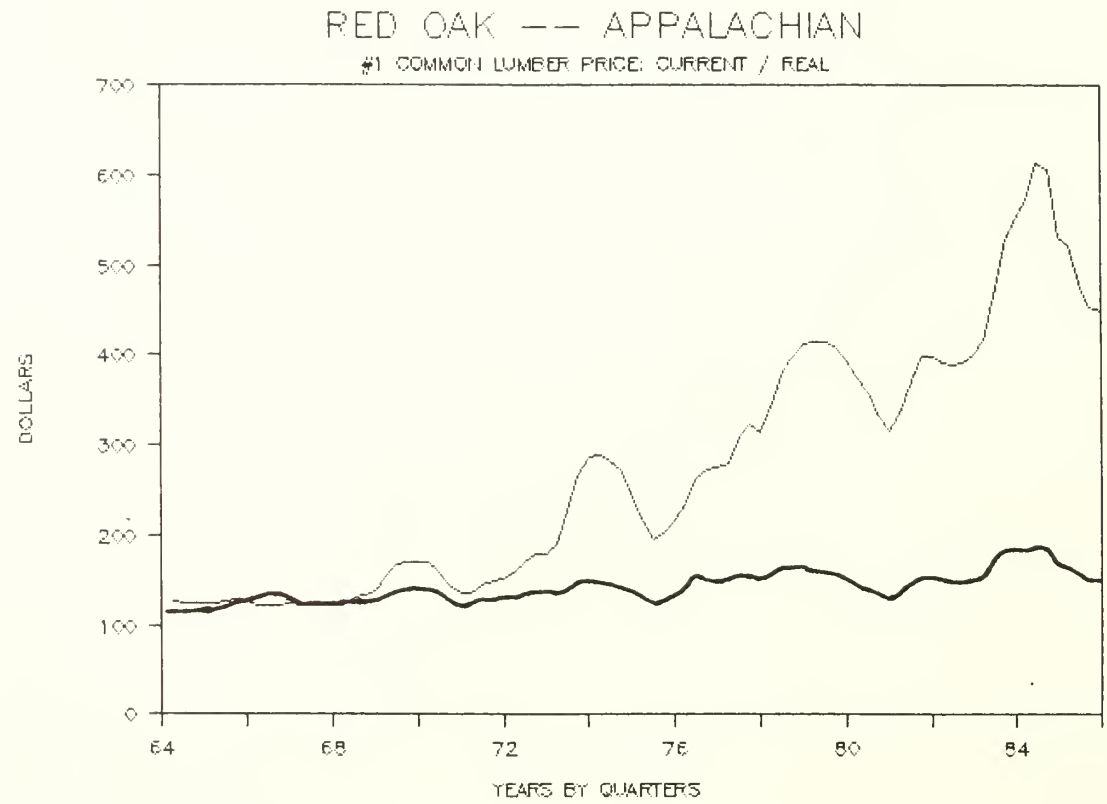
68
72
76
80
84
YEARS BY QUARTERS


RED OAK -- APPALACHIAN
#1 COMMON LUMBER PRICE: CURRENT / REAL
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64
68
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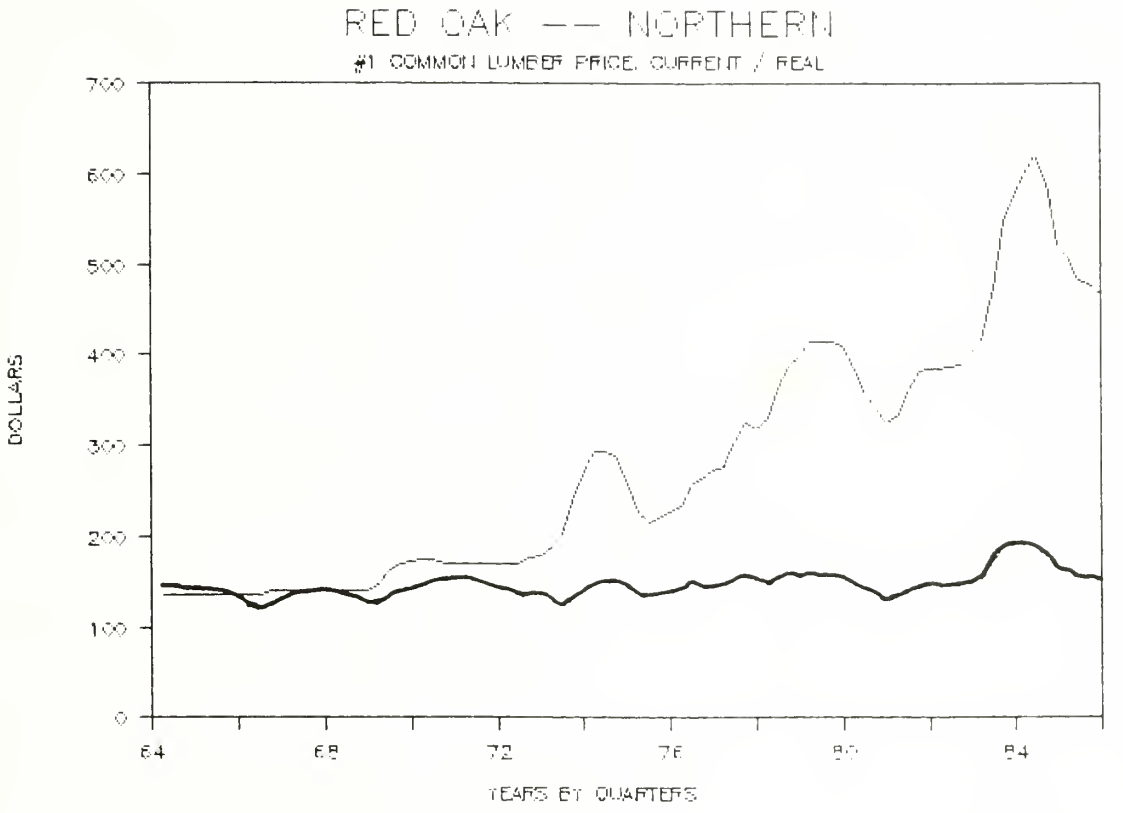
80
84
YEARS BY QUARTERS


RED OAK -- NORTHERN
#1 COMMON LUMBER PRICE, CURRENT / REAL
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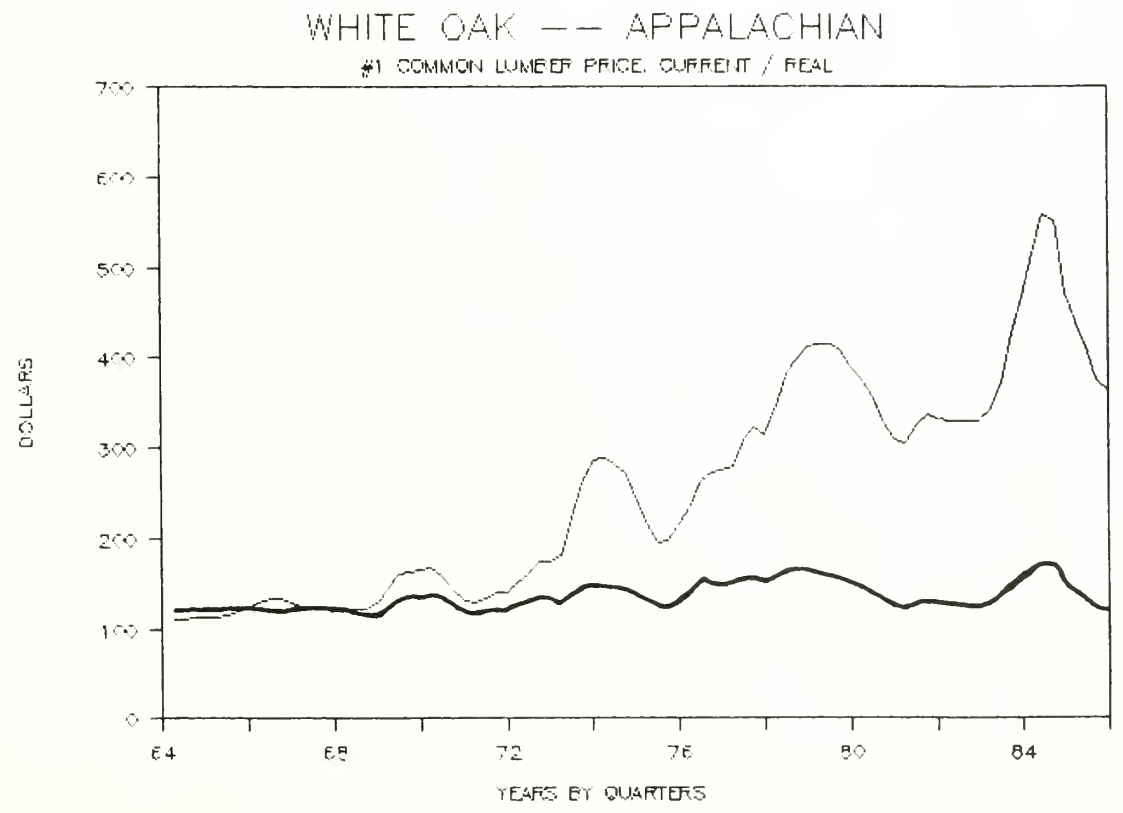
YEARS BY QUARTERS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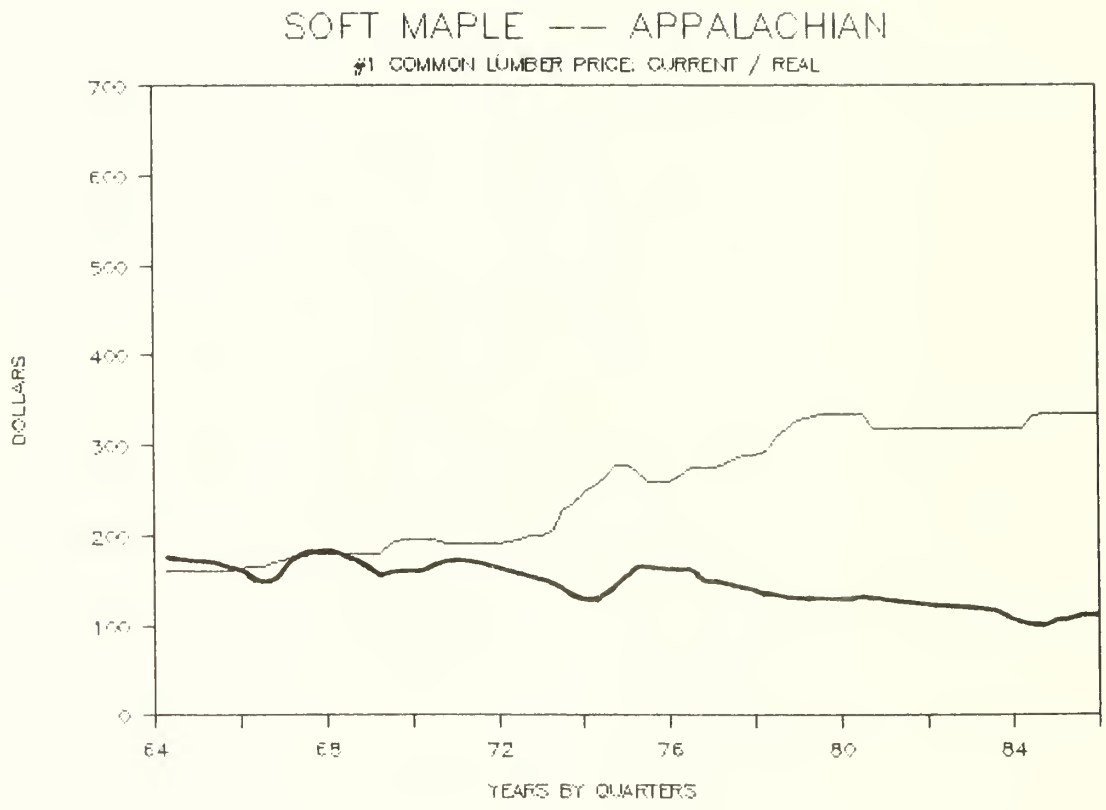
80
84
YEARS BY QUARTERS


SOFT MAPLE -- APPALACHIAN
#1 COMMON LUMBER PRICE, CURRENT / REAL
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200
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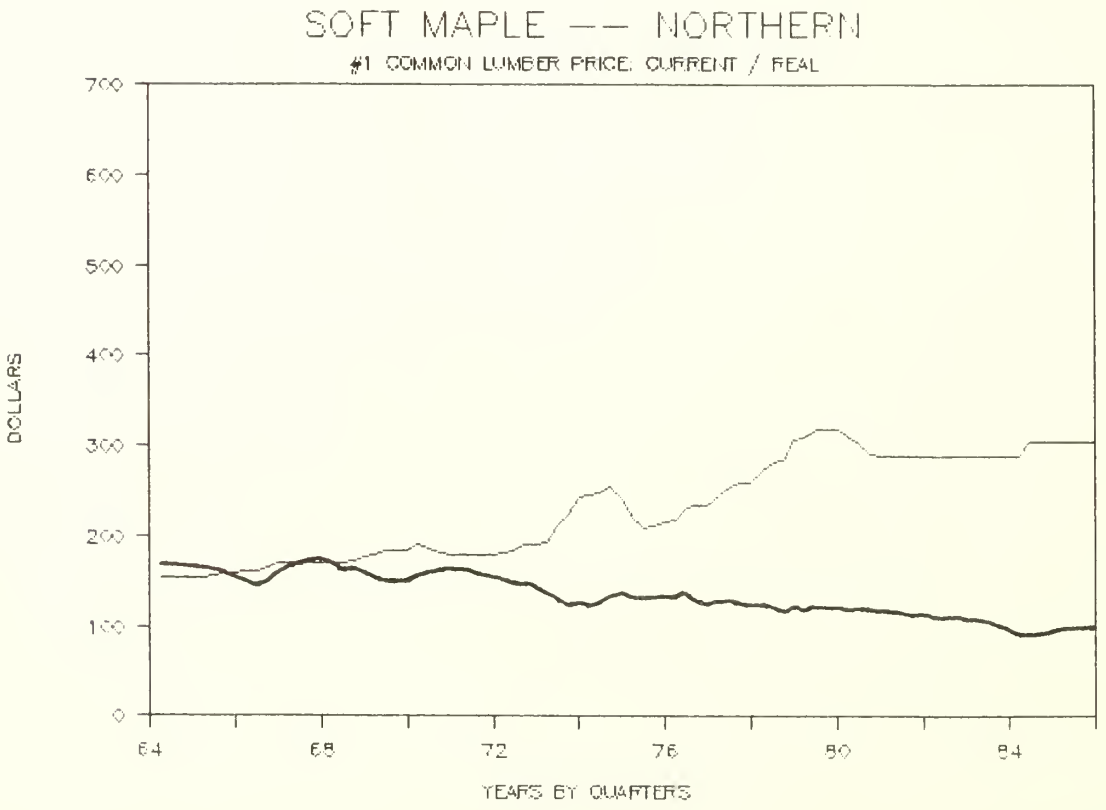
68
72
76
80
84
YEARS BY QUARTERS


SOFT MAPLE -- NORTHERN
#1 COMMON LUMBER PRICE, CURRENT / REAL
DOLLARS
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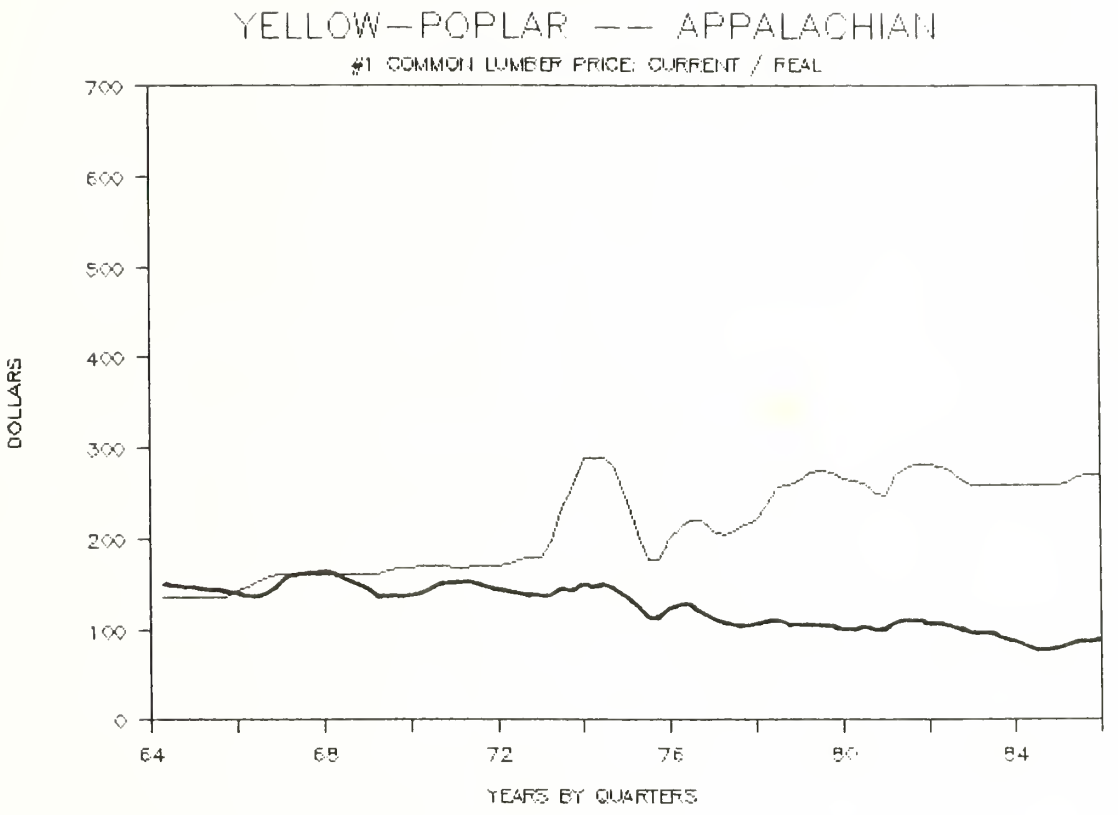
YEARS BY QUARTERS


YELLOW—POPLAR —— APPALACHIAN
#1 COMMON LUMBER PRICE: CURRENT / REAL
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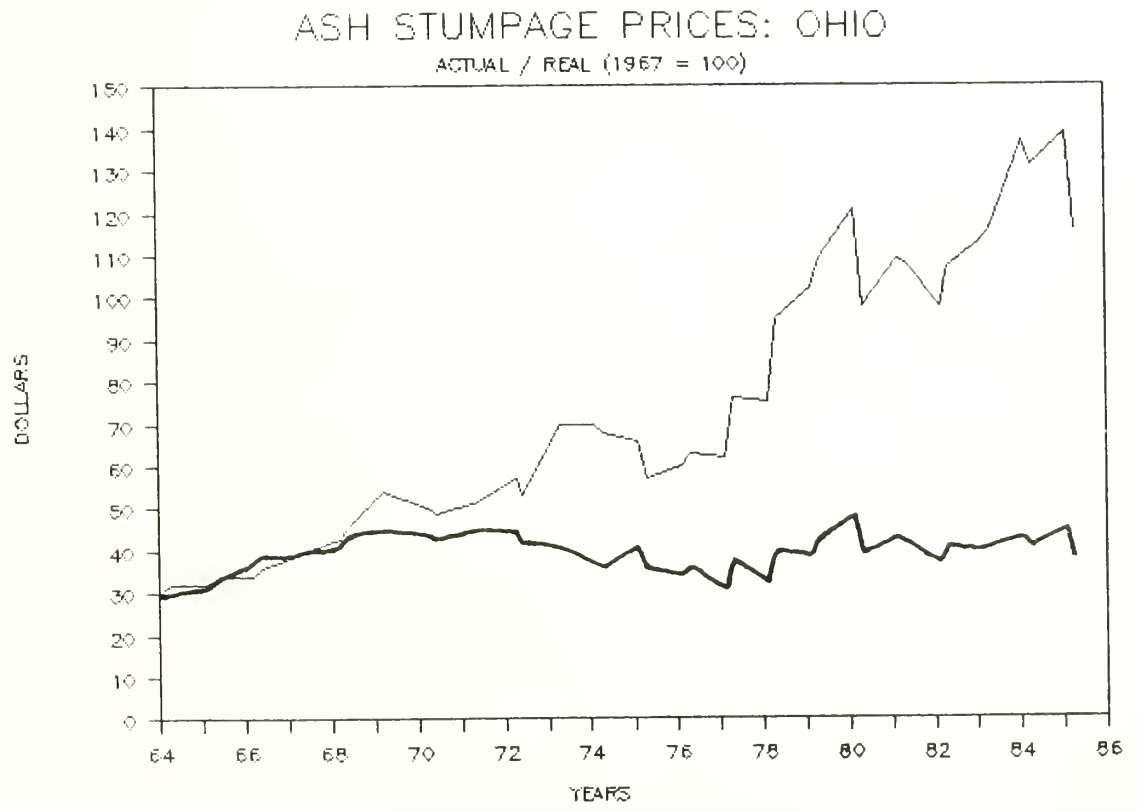
YEARS BY QUARTERS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ACTUAL / REAL (1967 = 100)
DOLLARS
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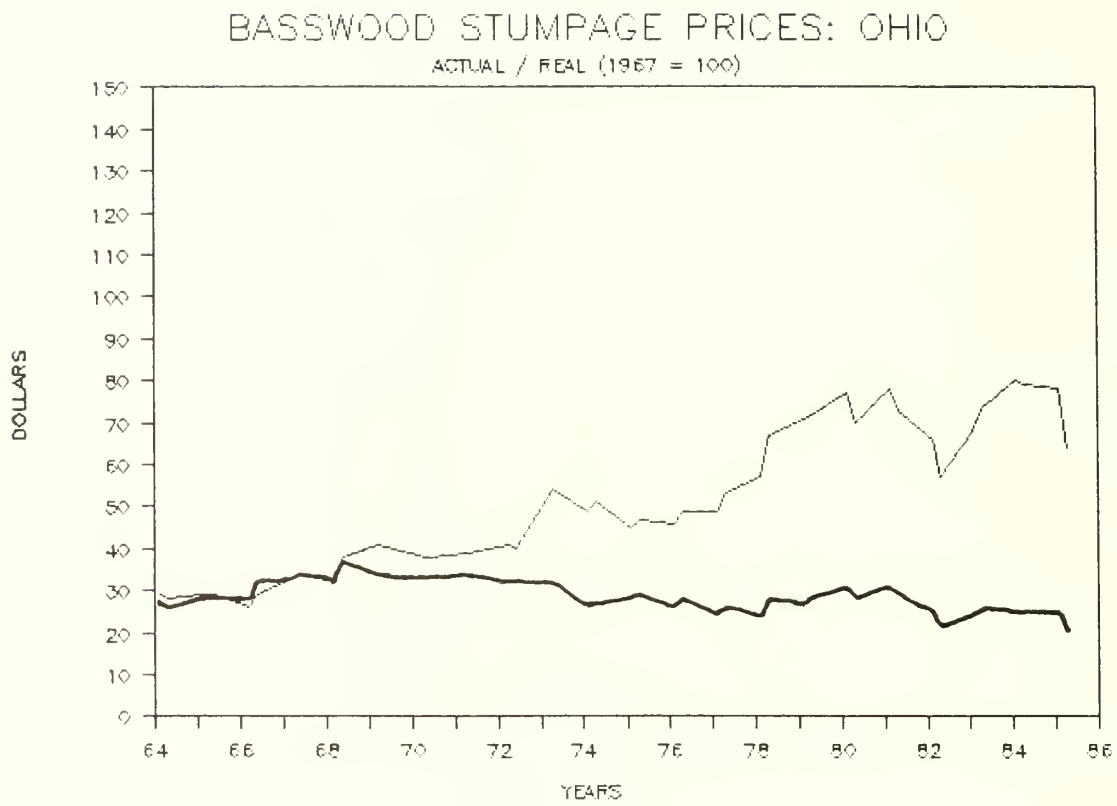
YEARS


BASSWOOD STUMPAGE PRICES: OHIO
ACTUAL / REAL (1967 = 100)
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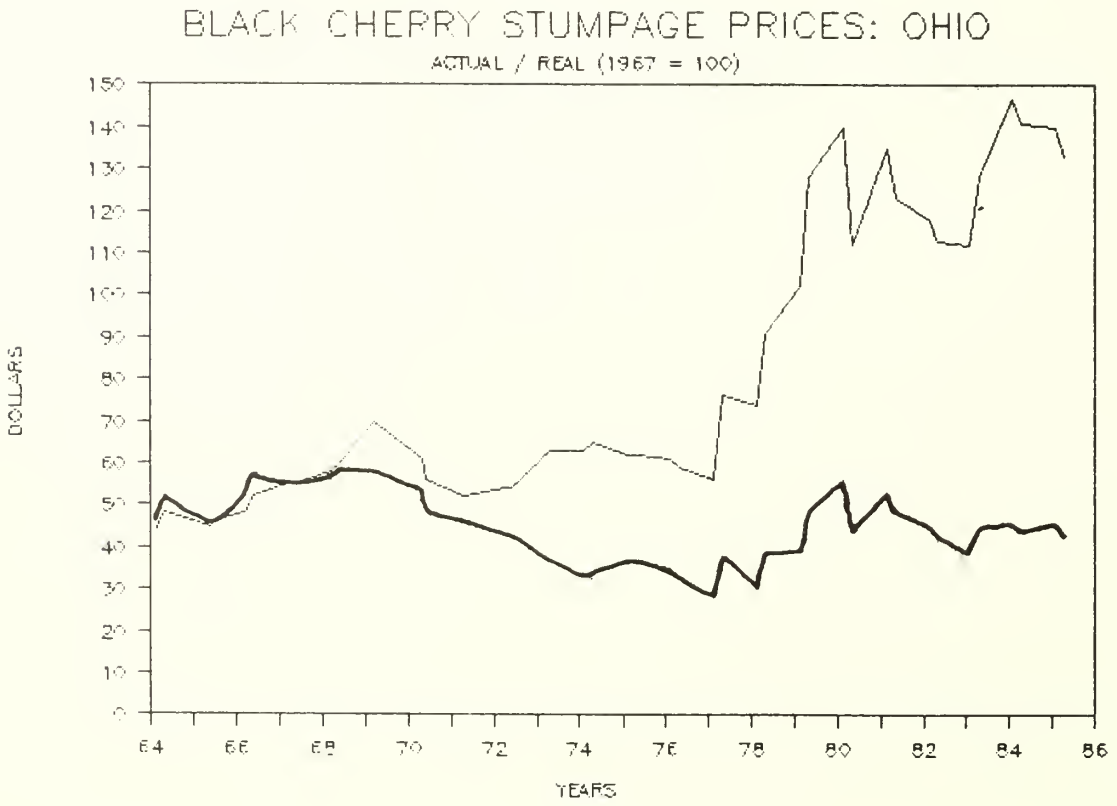
YEARS


BLACK CHERRY STUMPAGE PRICES: OHIO
ACTUAL / REAL (1967 = 100)
DOLLARS
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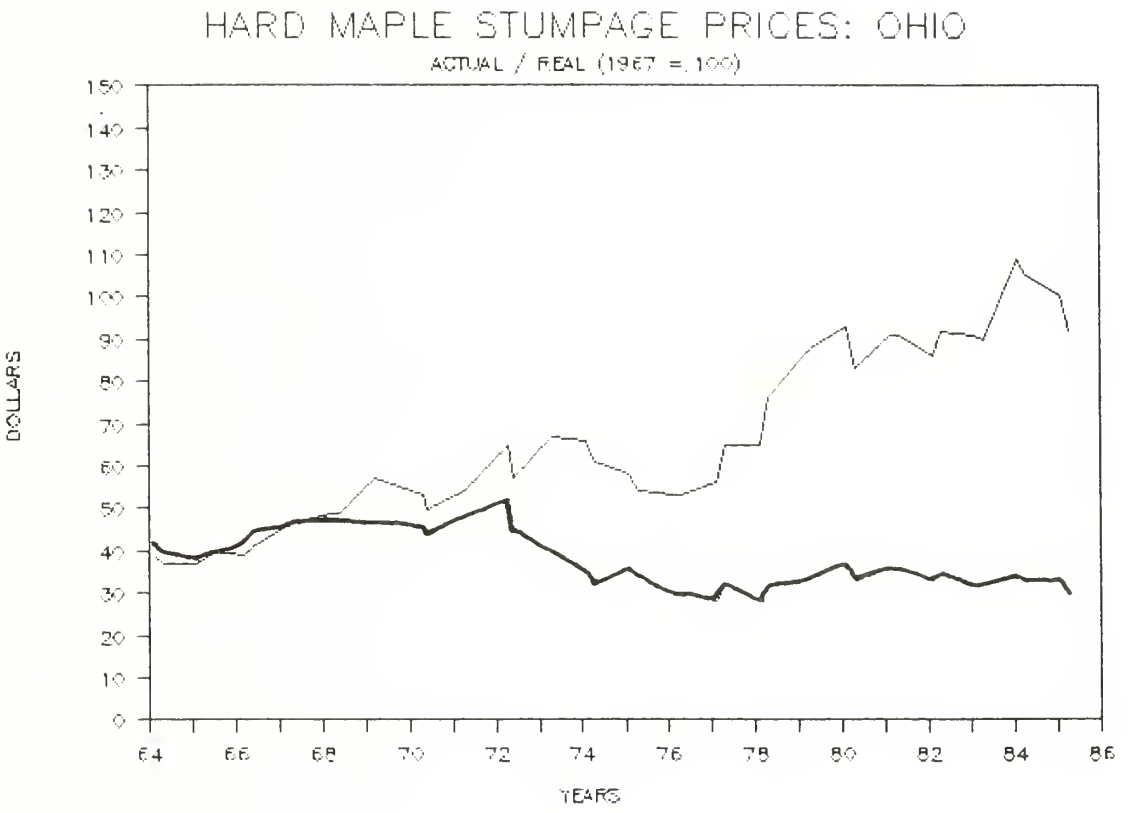
YEARS


HARD MAPLE STUMPAGE PRICES: OHIO
ACTUAL / REAL (1967 = 100)
DOLLARS
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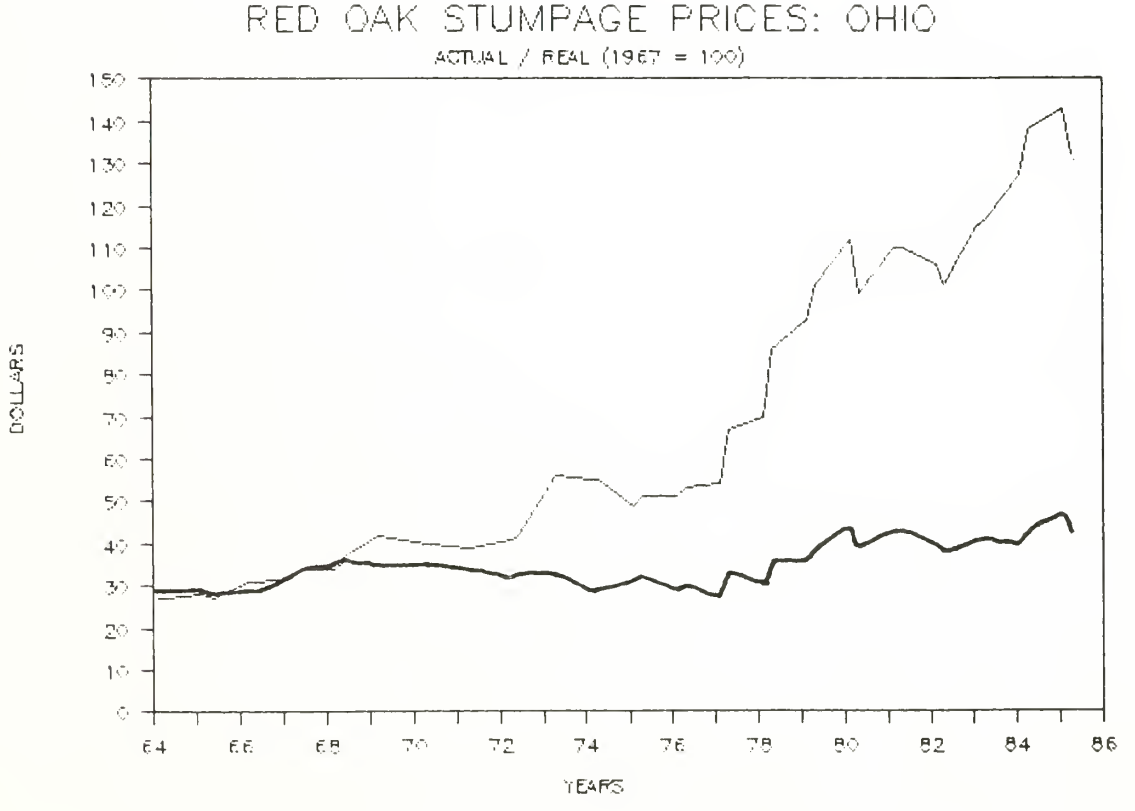
YEARS


RED OAK STUMPAGE PRICES: OHIO
ACTUAL / REAL (1967 = 100)
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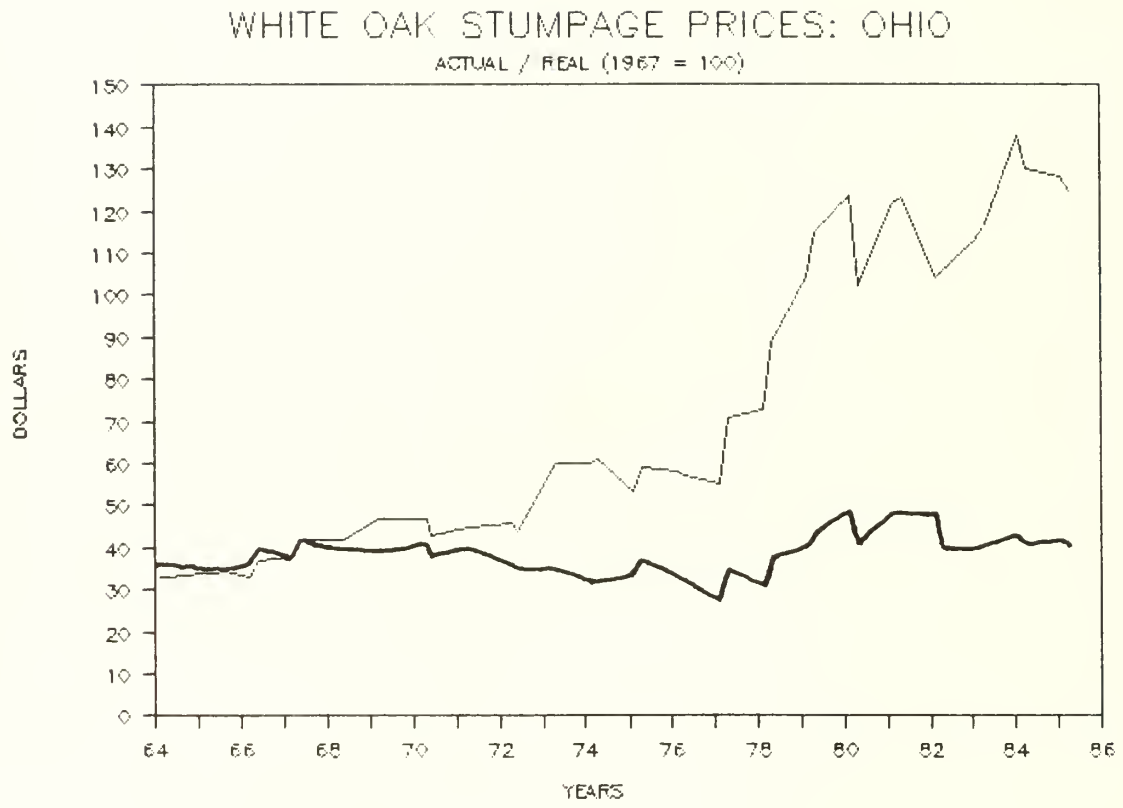
YEARS


WHITE OAK STUMPAGE PRICES: OHIO
ACTUAL / REAL (1967 = 100)
DOLLARS
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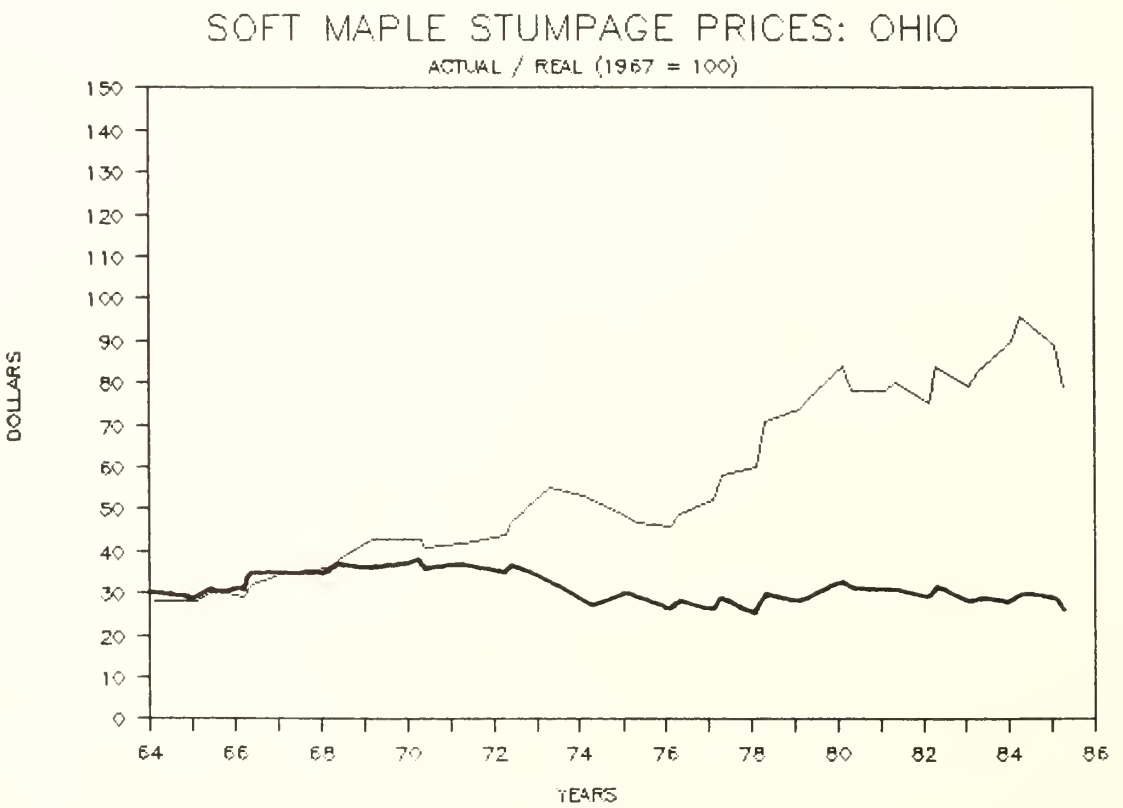
YEARS


SOFT MAPLE STUMPAGE PRICES: OHIO
ACTUAL / REAL (1967 = 100)
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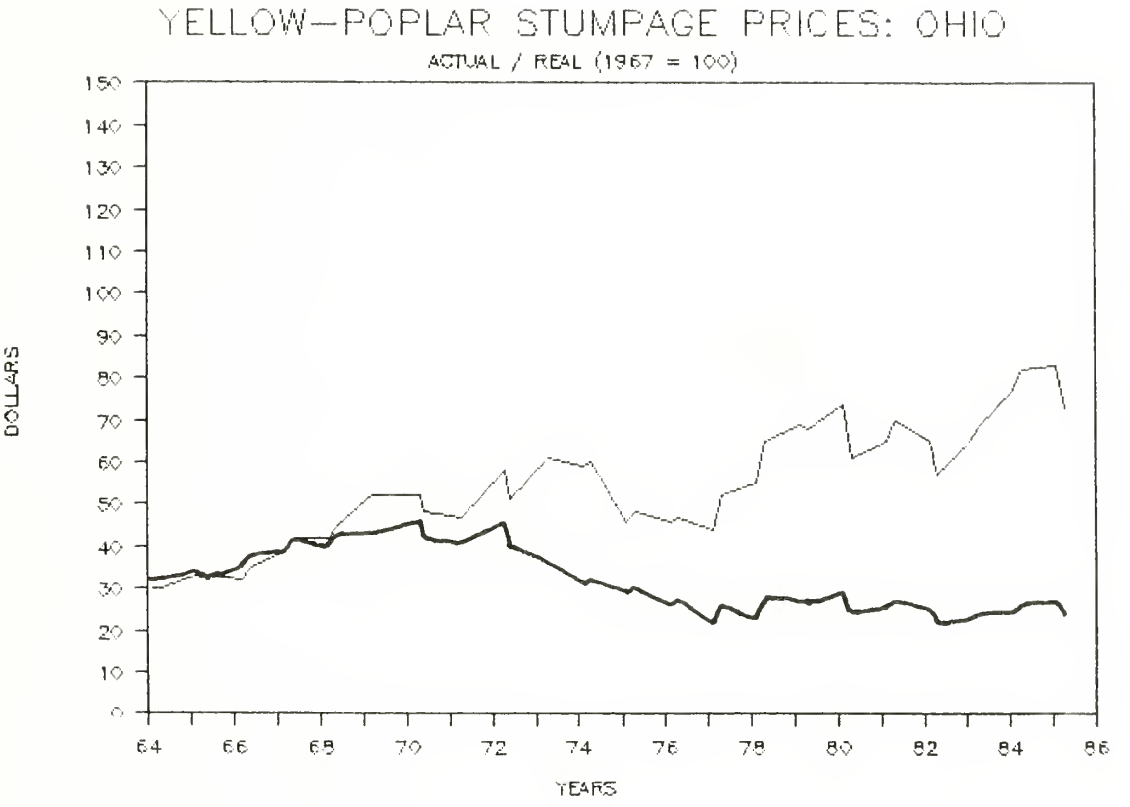

Kingsley, Neal P.; DeBald, Paul S. 1987. **Hardwood lumber and stumpage prices in two eastern hardwood markets: The real story.** NE-RP-601. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, 17 p.

Current and real prices of hardwood lumber and stumpage prices are discussed. Results show that inflation wiped out most of the apparent price increases in two major hardwood lumber markets. Stumpage prices also failed to increase in real terms for most species in Ohio. Current and real prices trends for eight major eastern species are shown for the period 1964 through 1985.

ODC 721

Keywords: Hardwood, lumber, stumpage, prices, eastern markets, market price, real price.

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**Northeastern Forest
Experiment Station**

NE-RP-602

AUG 1 2 1987
PUBLIC DOCUMENTS

FIBER HANDBOOK: A Growth Model for Spruce-Fir and Northern Hardwood Forest Types

Dale S. Solomon
Richard A. Hosmer
Homer T. Hayslett, Jr.

Abstract

A matrix model, FIBER, has been developed to provide the forest manager with a means of simulating the management and growth of forest stands in the Northeast. Instructional material is presented for the management of even-aged and multi-aged spruce-fir, mixedwood, and northern hardwood stands. FIBER allows the user to simulate a range of silvicultural treatments for a variety of species compositions growing on different sites. The internal structure of the model is defined and explanations on the use of FIBER are offered. Examples of input, interim procedures, and final output are shown.

The Authors

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Northeastern Forest Experiment Station
370 Reed Road, Broomall, PA 19008
June 1987

Introduction

A stand projection growth model, FIBER, was developed to predict the growth interactions among species within spruce-fir, northern hardwood, and mixedwood forest types (Solomon et al. 1986). This prototype model has been modifed by further testing of independent variables for the regression equations and by the inclusion of data sets from a broader geographical area, which allowed for additional species (Solomon and Hosmer 1986). The model allows the forest manager to simulate the growth of trees for management practices and silvicultural treatments over a range of stand densities, harvest intervals, species compositions, and sites. These options allow the user to predict the growth and yield, over a specified time interval, of either individual forest stands or large forested areas receiving similar management practices.

The species composition of the forest stands used in the construction of the model ranged from complete softwood stands to complete northern hardwood stands. Softwood stands were defined as those having at least 65 percent of their basal area in softwood species; hardwood stands had at most 25 percent of their basal area in softwood species; and mixedwood stands had 25 to 65 percent of their basal area in softwood species.

The species groups available in the model are:

Balsam fir	*Abies balsamea* (L.) Mill
Spruce	
Black	*Picea mariana* (Mill.) B.S.P.
Red	*Picea rubens* Sarg.
White	*Picea glauca* (Moench) Voss
Eastern hemlock	*Tsuga canadensis* (L.) Carr.
Northern white-cedar	*Thuja occidentalis* L.
Sugar maple	*Acer saccharum* Marsh.
Red maple	*Acer rubrum* L.
Yellow birch	*Betula alleghaniensis* Britton
Paper birch	*Betula papyrifera* Marsh.
American beech	*Fagus grandifolia* Ehrh.
White ash	*Fraxinus americana* L.
Aspen	*Populus tremuloides* Michx.
Other hardwoods	
Gray birch	*Betula populifolia* Marsh.
Striped maple	*Acer pennsylvanicum* L.
Pin cherry	*Prunus pensylvanica* L.F.
Black ash	*Fraxinus nigra* Marsh.
Other softwoods	
Tamarack	*Larix laricinia* (Du Roi) K. Koch
White pine	*Pinus strobus* L.

The data used to develop this model came from a wide range of site conditions across the Northeast. The model was constructed to cover a range in the site indices of 30 to 70 for softwood, 35 to 75 for mixedwood, and 40 to 80 for hardwood at base age 50 years.

Some of the stands used for the model development were the result of harvesting practices that resembled different forms of forest management. Other stands, primarily the softwoods, were natural stands that had developed with only occasional management. As a result of the range in management practices, FIBER can be applied within both even-age and multi-age types of management.

Softwood, mixedwood, and hardwood stands can be managed or controlled within the model by allowing the stand to grow to a specified stocking level, as measured by square feet of basal area or cubic volume, or by allowing the stand to grow for a specified time (years). The forest manager can control the level of residual basal area and cubic volume through thinning, by specifying a desired level or by using B lines as presented in the stocking charts (Figs.1–3). The quality line for hardwoods may be used to maintain a higher density and better quality in younger and smaller diameter stands (Solomon and Leak 1986).

Thinning practices that can be used in the program include: thinning from above, thinning from below, thinning to a q-line (de Liocourt 1898), removal of trees from any diameter class, or thinning uniformly across all diameter classes.

Sources of Data

Beginning in 1953, a series of 359 permanent plots was established within a softwood forest on the Penobscot Experimental Forest, Bradley, Maine. The 1/5-acre (0.08–ha) plots were both randomly and systematically located within forest stands (compartments) to be used for various silvicultural practices. Harvests were conducted in each compartment at 5-, 10-, or 20-year intervals (Frank and Blum 1978). Each plot was remeasured at 5-year intervals regardless of harvest cycle; if there was a harvest, the plot was remeasured both before and after the harvest.

A study of multi-aged northern hardwoods was begun in 1964 using forty-eight 1/3-acre (0.14–ha) plots (Solomon 1977) located on the Bartlett Experimental Forest, Bartlett, New Hampshire. Each plot was measured, thinned uniformly across size classes to a predetermined residual basal area and size structure, and remeasured at 5-year intervals, as in the softwood study.

Independent data sets of more than 2,500 growth plots from northern Maine, New Hampshire, northern New York, and Vermont also were included to increase the flexibility and reliability of the prototype model (Solomon et al. 1986). Each plot was measured from 1959 to 1974 at 5-year intervals; the data sets covered a wide range of species compositions, sites, management options, and densities (Fig. 4).

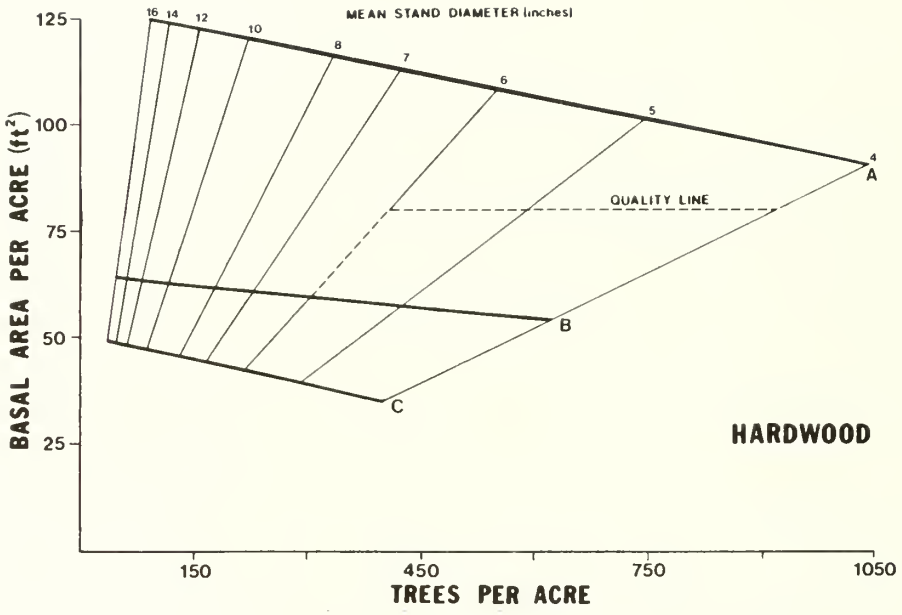

Figure 1.—Stocking chart for northern hardwoods is based on trees in the main crown canopy. The A line is average maximum stocking. The B line is recommended minimum stocking for adequate growth response per acre. The C line defines the minimum amount of acceptable growing stock for a manageable stand. The quality line defines the stocking measure in young stands for maintaining quality development.

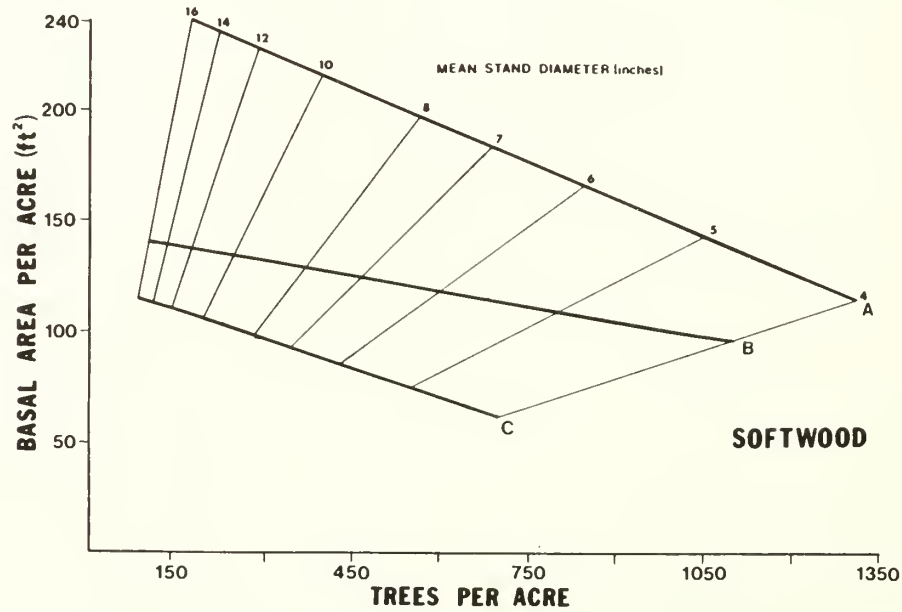

Figure 2.—Stocking chart for spruce-fir stands is based on trees in the main crown canopy. The A line is average maximum stocking. The B line is recommended minimum stocking for adequate growth response per acre. The C line defines the minimum amount of acceptable growing stock for a manageable stand.

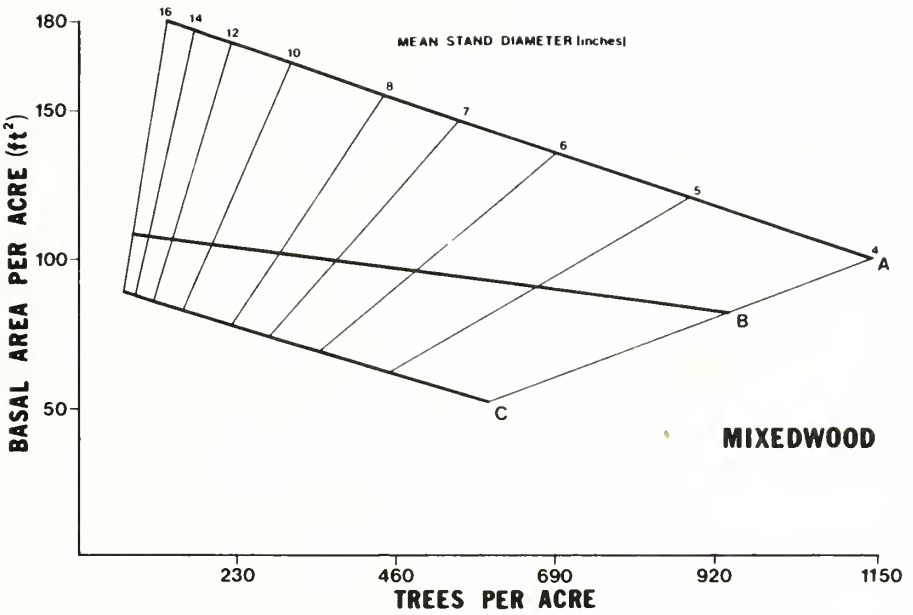

Figure 3.—Stocking chart for mixedwood stands is based on trees in the main crown canopy. The A line is average maximum stocking. The B line is recommended minimum stocking for adequate growth response per acre. The C line defines the minimum amount of acceptable growing stock for a manageable stand.

In the Northeast, softwood stands often are found on poorer sites, and northern hardwood stands on better sites, with a mixture of both species on intermediate sites. The soils on sites used for study locations ranged from poorly drained to well drained.[1] Site index was not calculated for each plot within the data sets. However, some softwood stands had site indices of 40 to 50 for red spruce at base age 50 years, and hardwood stands had site indices of 50 to 60 for sugar maple at base age 50 years. The data ranged from the poorer spruce-cedar stands to the better, pure northern hardwood stands. An expression of site index was not included as a variable in the development of FIBER since site measurements were not recorded on all plots used in model construction.

Model Definitions

FIBER is a two-stage matrix model. One stage of the model is a set of linear regression equations that predict transition probabilities of tree growth and mortality as a function of stand density, tree size, and proportion of hardwoods.

[1] For definitions of poorly drained and well drained see the county soil surveys published by the USDA Soil Conservation Service.

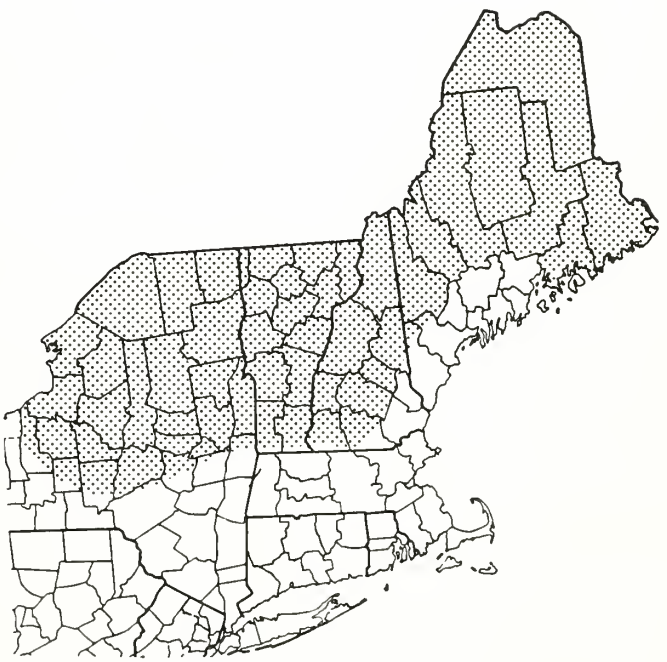

Figure 4.—Dotted area is geographic region of growth-plot data used for model construction and testing.

These predicted probabilities are the elements of stand projection matrices that are used to project the distribution of stand diameters over a 5-year period (Solomon et al. 1986). This two-stage matrix model is a modification and extension of an earlier matrix model (Buongiorno and Michie 1980).

For each species, a matrix G_t of transition probabilities was applied to a stand table vector y_t, which displays the number of trees of that species in each d.b.h. class. By adding the ingrowth, these two operations generate the stand table vector after 5 years of growth for each species:

$$(1) \qquad y_{t+5} = G_t\, y_t + I_t$$

where

$$G_t = \begin{bmatrix} a_{5,t} & 0 & 0 & 0 \ldots \\ b_{5,t} & a_{6,t} & 0 & 0 \ldots \\ c_{5,t} & b_{6,t} & a_{7,t} & 0 \ldots \\ 0 & c_{6,t} & b_{7,t} & a_{8,t} \ldots \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \end{bmatrix} ; \quad I_t = \begin{bmatrix} k \\ 0 \\ \cdot \\ \cdot \\ \cdot \\ 0 \end{bmatrix},$$

with

$a_{i,t}$ = the probability that a tree survives and is in the i^{th} diameter class during the time interval from t to t + 5;

$b_{i,t}$ = the probability that a tree survives and is in diameter class i at time t and in diameter class i + 1 at time t + 5;

$c_{i,t}$ = the probability that a tree survives and is in diameter class i at time t and in diameter class i + 2 at time t + 5; and

k = ingrowth into the 5-inch class during the time interval from t to t + 5.

The data sets described earlier were combined. Tree diameters were measured at 4.5 feet (1.3 m) and placed in 1-inch classes, which ranged from 5 to 30 inches (12.7 to 76.2 cm). In subsequent inventories, each tree on the plot was categorized as ingrowth, survivor, or mortality (m). For a given plot, the diameter distribution for any one species was sparse; therefore, the pooling of plots was required to obtain more reliable estimates of a, b, c, and m. Because the growth response of forest stands may vary by magnitude of change in density (Solomon 1977; Solomon and Frank 1983), the plots were categorized by both the initial basal area (IBA_t) prior to harvest and the residual basal area (RBA_t) after a harvest. If there was no harvest at time t, the IBA_t and RBA_t were the same. The plot data were grouped by basal area in 20 ft^2/acre intervals. The range from 20 to 260 ft^2/acre (4.6 to 59.6 m^2/ha) of basal-area categories for these data sets was sufficient to provide growth response information for the general management alternatives. The plots grouped in any specific IBA–RBA category were considered to have the same growth rate.

For each species, linear equations were developed to predict: ingrowth into the smallest class (k); the probability of a tree remaining in its present diameter class (a_{it}); the probability of a tree growing into the next diameter class (b_{it}); the probability of a tree growing two diameter classes larger (c_{it}); and the probability of a tree dying (m_{it}). Note that the mortality rate is not included in the G_t matrix but is inherent in the model since $m_{it} = 1.0 - a_{it} - b_{it} - c_{it}$.

The set of probabilities associated with diameter class i is assumed to have a multinomial distribution, and is modeled by linear functions of the form:

$$a_{it} = \beta_{01} + \beta_{11}\, IBA_t + \beta_{21}\, RBA_t + \beta_{31}\, D_i + \beta_{41}\, P_t + \beta_{51}\, D^2_i + \beta_{61}\, RBA^2_t$$

$$b_{it} = \beta_{02} + \beta_{12}\, IBA_t + \beta_{22}\, RBA_t + \beta_{32}\, D_i + \beta_{42}\, P_t + \beta_{52}\, D^2_i + \beta_{62}\, RBA^2_t$$

$$c_{it} = \beta_{03} + \beta_{13}\, IBA_t + \beta_{23}\, RBA_t + \beta_{33}\, D_i + \beta_{43}\, P_t + \beta_{53}\, D^2_i + \beta_{63}\, RBA^2_t$$

$$m_{it} = \beta_{04} + \beta_{14}\, IBA_t + \beta_{24}\, RBA_t + \beta_{34}\, D_i + \beta_{44}\, P_t + \beta_{54}\, D^2_i + \beta_{64}\, RBA^2_t$$

where

IBA_t = initial stand basal area prior to harvest at time t (ft^2/acre),

RBA_t = residual stand basal area after harvest at time t (ft^2/acre),

D_i = midpoint of the diameter class i (inches),

P_t = proportion of hardwoods in the stand at time t, and

β_{jk} = regression coefficients to be estimated.

The entries of G_t can be found from these equations using the coefficients in Table 1 of the Appendix that were developed from the combined data sets of softwood, mixedwood, and hardwood.

Not all of the species in the data sets ranged to the same maximum-size diameter and did not have a sufficient number of trees in the larger diameter classes. Thus, the a, b, c, and m equations did not accurately describe the movement of trees in these larger classes. To decrease the growth rate and increase the mortality of the larger trees

over time in mature stands (RBA > 125 ft^2/acre), the a-, b-, and c- values were linearly reduced from the predicted equation value to zero within the range of the maximum-size diameter classes of each species (Table 2). The amount removed from these transition probabilities was added to mortality (m) as the stand matures, ensuring that partial trees will not accumulate in the 30-inch class.

To model differences in growth rate due to species composition on different sites, the b- and c-values were modified if the site index value differed from the average value of that forest type:

$$b^* = b\ SI/x \quad \text{and} \quad c^* = c\ SI/x$$

where

SI = site index,

$$x = \begin{cases} 50 \text{ for softwood stands} \\ 55 \text{ for mixedwood stands} \\ 60 \text{ for hardwood stands.} \end{cases}$$

Then

$$a^* = a\ (1.0 - m)/(a + b^* + c^*)$$

$$b^{**} = b^*\ (1.0 - m)/(a + b^* + c^*)$$

$$c^{**} = c^*\ (1.0 - m)/(a + b^* + c^*).$$

This procedure assures that a^*, b^{**}, and c^{**} are all less than 1 and that $a^* + b^{**} + c^{**} + m = 1.0$. It also leaves mortality unaffected by site index.

When the stand reaches age 80 or the number of iterations equals 80 years, the "shorter lived" species of paper birch, aspen, and other hardwoods are forced out of the stand. The c-value is forced to zero by 100 years, the b-value by 110 years, and the a-value by 130 years. All of the amounts removed are added to mortality (m). If the RBA falls below 60 ft^2/acre, ingrowth trees of these species are allowed to enter and grow in the stand for another 80 to 130 years.

For ingrowth, a threshold diameter of 5.5 inches (14.0 cm) was used for one large data set and 4.5 inches (11.4 cm) for the other smaller data sets. After testing several variables and combinations of variables, separate linear equations were developed for each species:

$$k = \alpha_0 + \alpha_1\ RBA_t + \alpha_2\ P_t + \alpha_3\ PS_t,$$

where PS_t is the proportion of that species in the stand at time t (Table 1).

Model Reliability

To validate the predictions of the model, the data set was stratified by species and forest type. The actual growth on each plot was compared to the predicted growth over a 15-year period (Table 3). The predicted final volume differed from the actual volume by 0.8 to 14.1 percent. The poorest predictions were in the lowest basal-area categories. This was primarily due to large amounts of ingrowth, but predictions are expected to improve as more data sets are included.

Overall, the model predicted the growth of softwood and hardwood stands more accurately than the growth of mixedwood stands. This, too, is to be expected since detailed studies have not been conducted in mixedwood stands. As the results of thinning studies in smaller size stands become available, the predictabilty of the lower basal-area categories should improve.

The largest differences between the actual and predicted values are for balsam fir and spruce in hardwood and mixedwood stands. Since the harvesting practices and true site were not known for every plot, some softwood plots could have been considered as hardwood stands after thinning. The softwood species may have been removed, leaving the residual hardwood in the remaining stand. Thus, more spruce and fir ingrowth resulted in the actual stand than in the predicted stand.

Model Application

The model projects forest stands through time in 5-year intervals (Fig. 5). The user can input an inventory of one or several stands and grow these stands for the entire rotation period or for any specified number of years. FIBER will prompt the user with a menu that will determine the scope of each run. A control file that stores all of the information pertaining to each run is written to disk. The user is asked to provide the file name of this control file and whether it is a new or existing file. On subsequent runs, the user can use this file to duplicate an earlier run, modify the file to meet new criteria, or create a new set of control information. There also is the opportunity to select either the printer or a disk file as the primary output device.

The user is asked to choose from one of the options from the following menu:

(1) HELP	(7) SITE INDEX
(2) NEW CONTROL	(8) PERCENT CULL
(3) TITLE	(9) THINNING
(4) STOCKING	(10) DISPLAY CONTROL
(5) GROWTH PERIOD	(11) DISPLAY STAND
(6) STAND AGE	<12> EXECUTE

Option 12 is the default value and will be in effect if a carriage return is entered. There are default values to a variety of questions in this section and they are all designated on the console by being enclosed in < >. Entering a minus sign in response to any question will terminate the program.

Option (1):

Help — A summary of instructions for creating a control file will be printed on the console. After every 15 to 20 lines, the program waits for a carriage return to be entered before continuing.

Option (2):

New — An entire control file containing the information requested in options 3 through 9 will be created. If a file of this name already exists, the user will be given the choice of renaming the file, returning to the menu, or continuing, which will cause the existing file to be destroyed.

A first-time user should only use options 1 or 2 to start. Options 3 through 9 allow you to modify the control file without creating a new file.

Option (3):

Title — A title for this run that will appear at the top of each page of output.

Option (4):

Stocking choice — A list of the species that will be allowed in this stand projection must be supplied. This is accomplished by entering a one (1) for the species to be included and a zero (0) for species not included.

There are three choices for inputting the initial stand diameter distribution.

(1) User inputs diameter lists for each species. The program prompts the user by giving the species and asking for the number of trees in each diameter class of 5 through 17 inches on the first line, and then asking for the entries for the 18- through 30-inch diameter class on a second line. A carriage return will enter zeros for the remainder of the line. The model uses real numbers so fractional parts of a tree may be entered. However, any entry less than 0.1 is changed to a zero.

(2) The user is prompted to input the total number of stems for a given species and the percentage of these trees in diameter classes 5, 6, 7, 8, 9, 10, 11, 12, 13 to 15, 16 to 19, and 20+. These percentages are checked to see if they total 100; if they do not, the user is asked to re-enter them.

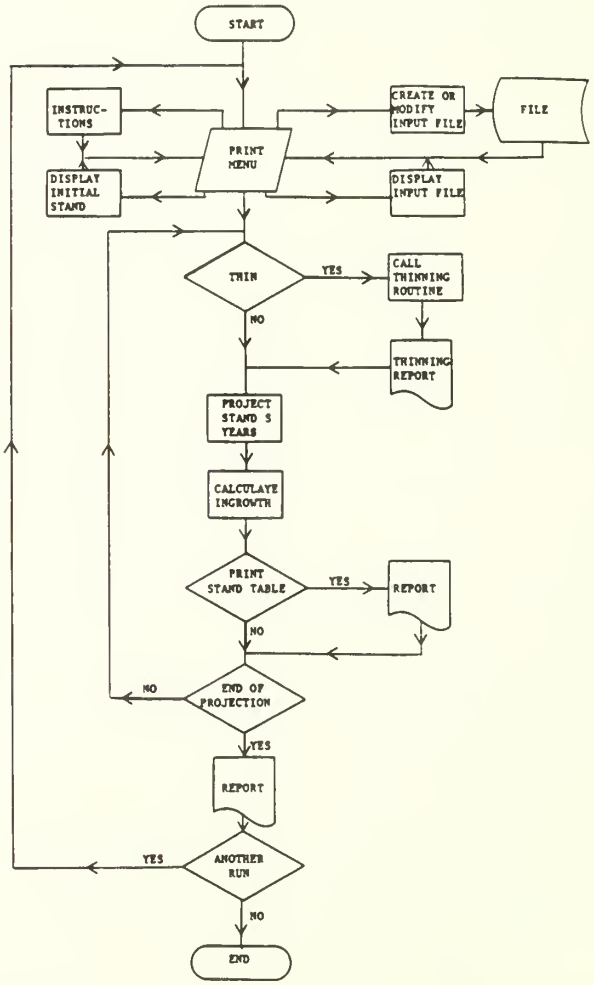

Figure 5.—General logic for main program of FIBER.

<3> The user can input several plots of various sizes and obtain an average plot to represent the initial stand. These plots can be a mixture of fixed plots or prism plots. If they are fixed plots, the user must supply the inverse of the plot size. For prism plots, the basal-area factor must be given. This option also allows the user to enter the tree list in 1- or 2-inch diameter classes. The stand entered in 2-inch classes will be adjusted into 1-inch classes programmatically.

The diameter classes by species are displayed on the terminal and the user may modify the stand, if desired. The modification process redisplays the stand information just entered, species by species. The user can change the entries for each species or preserve the values by entering a carriage return. After checking each species group, the stand is again displayed and the user is given the choice of further modification or continuing with entering other projection information.

Option (5):

Report interval	The number of years of growth between the stand table reports sent to the printer. This must be a multiple of 5 years. The default value is 10 years.
Projection length	The total number of years that the model is to grow the stand. This, too, must be a multiple of 5 years.
Harvest diameter	The quadratic mean stand diameter of the stand when it is harvested. The model will continue to grow the stand until it reaches this diameter or reaches the projected age.
Managed/ unmanaged	Will thinning operations be conducted? (Y), <N>.

Option (6):

Even-aged/ multi-aged	Is the stand managed as an even-aged or multi-aged stand.
Stand age	For even-aged stands, enter the age. For multi-aged stands, enter the approximate number of years since the last major harvest, or a carriage return <cr> will continue the program if this information is not available.

Option (7):

Forest type	If the forest type and site are known as spruce-fir or northern hardwoods, the model will operate within the range of the specified type regardless of the species present. If the forest type is unknown, the model will determine the forest type based on the initial stand composition.
Site index	Enter the site index for the stand within the following ranges for each forest type: softwood 30 to 70, <50> hardwood 40 to 80, <60> mixedwood 35 to 75, <55>.

Option (8):

Percent cull	The percentage of sawtimber for each species that can be considered as cull and be moved to the pulpwood category upon harvesting. The default value, <cr>, will enter zero values for cull.

Option (9):

Thinning specification	The user can choose to control the thinning by square feet of basal area or cubic feet of volume.
When to thin	There are two ways to control when to thin the stand. One choice is to specify the number of years to run prior to thinning (0, 5, 10, 15. . .). The other choice is to specify a basal area or volume level for the stand to attain before thinning.
Interactive/ batch thin control	If the user desires, the model will stop before each thinning, display the stand and ask for any silvicultural treatment desired. This process is referred to as the "interactive" control and, if chosen, the input phase is ended and control is returned to the menu.

If the user chooses to specify a treatment for the entire projection period, the model will not display the thinning information to the terminal but will send it to the printer. This version is the "batch" option.

Silvicultural treatment

No thinning—this is the default value; it causes the model to grow the stand until the next thinning (if in the interactive mode) or continue until the end of the projection (if in the batch mode).

Thin from above—the amount of basal area or cubic feet to remove from each species is specified. The model begins removing trees from a user-specified diameter class and continues to smaller classes until the specified residual level is reached or until a species has been completely harvested. If a species is removed, the remaining amount to be thinned is distributed over the species with the highest priority.

Thin from below—similar to thinning from above except that the process begins at the user-specified diameter class and works to larger classes.

Diameter class removal—if the user is controlling the thinning interactively, this option allows the user to specify the number of trees to remove from a given species and diameter class.

Uniform thinning—the amount to thin for each species is divided evenly among all diameter classes with at least 0.1 of a tree. If a given diameter class does not have enough trees in it to satisfy the thin, the remaining amount to be thinned is distributed evenly over the remaining diameter classes. Once a species is completely removed by thinning, the remaining amount is divided among the species with the highest thinning priority.

q-line thinning—refers to a value that gives the slope of a negative exponential curve using the diameter distribution of your stand. This term was first used by de Liocourt (1898) and a method of calculating q is given by Leak (1963). This method can only be used for multi-aged stands. A theoretical tree distribution is developed with the same q-value as the current stand. This stand will have the desired basal area after thinning and will have no entries larger than a user-specified maximum diameter class for the stand. The number of trees to remove is then calculated for each diameter class by calculating the difference between the actual tree list and the theoretical tree list. The trees are removed from the stand according to a priority list. After this first pass, the user has the option to lower the 2-inch q-value by 0.1 if the stand structure has not met the management objective. The residual basal area and stand structure are given and the user can lower the 2-inch q-value by 0.1 for a second time. The stand values are presented and no further thinning is allowed without a growth period.

Maximum diameter class

Users who specify thinning to the q-line are asked to enter a maximum diameter class to retain in the stand. If this is less than the largest class in the current stand, all trees above the specified class will be removed. If the specified value is larger than any tree in the stand, the stand may be at a lower stocking level than specified after thinning. For thinning from above, the user gives a diameter class for the thinning to start and then smaller diameter classes are thinned. Thinning from below is similar except the thinning starts in the specified size class and then moves to larger classes.

Thinning level to retain

If q-line thinning was specified, the user is asked to input the desired level of basal area to retain. For the other thinning modes, the user has two choices depending on the type of management. One choice is to specify the residual stand in either basal area or volume, depending on the response to the thinning specification question earlier. The second choice, for even-aged stands, is to thin to the B line, based on stocking charts for softwood, mixedwood and hardwood stands (Figs. 1–3).

Percentage to thin

For thinning from above, from below, or uniformly, a percentage of the total amount to remove must be specified and is then taken from the species. These values range from 0 to 100 percent with the sum of all species groups totaling 100 percent. By changing these percentages the user can fully control removals from the stand. If the percentage to be removed from any species category is greater than the amount contained in it, the remainder is divided among the species with the highest priority of removal.

Priority thinning list

The user is asked to specify a priority of removal for each of the species groups in a range of 1 (low) to 9 (high). The same priority may be specified for more than one species group. If q-line thinning was chosen, these priorities are used to determine which species to remove first to obtain the desired diameter distribution. For thinning from above, below, or uniformly, this priority list is used only when, for a particular species, the percentage to thin times the amount to remove gives a value that is more than is present in that species. The excess amount to remove is then reassigned to other species by first considering species that had been targeted for thinning (by giving a nonzero percent-to-thin value) and that have the highest priority. If these species have not been totally removed, the extra amount to remove will be divided evenly among those with the highest priority; otherwise the next lower priority species on the "to be thinned" list are considered. If all of the species that are on the thin list have been removed, the extra amount is taken from species not previously targeted for thinning, according to priority.

If the thinnings are being controlled interactively, after each thinning the user is given the option of returning to the prethinning conditions to attempt an alternative method.

At this point, the control file on disk is complete and control is returned to the menu. The remaining options are:

Option (10):

Display control	Displays the contents of the control file named at the beginning of this run.

Option (11):

Display stand	Prints the initial stand table on the console and a chance to modify is given.

Option <12>:

Execute	Starts the growth projection according to the criteria contained in the control file.

An example of creating a control file for a hardwood stand and sample terminal output are shown in Table 4 (items in italics are entered by the user). The yield tables for intermediate thinnings and standing and total yields are given. The volume and board-foot values are obtained from local tables for the Penobscot Experimental Forest (softwood species) and the Bartlett Experimental Forest (hardwood species).[2] The cubic foot sawlog volume includes the whole tree, whereas the board-foot volume represents only sawlog material and not the volume of the tops. In order to estimate the top volume, the board-foot volume should be converted to cubic feet and subtracted from the total cubic feet in sawlog volume. At the end of a projection the user is asked if he or she desires another run on this control

[2] Volume and board-foot values were determined using the International 1/4-inch rule.

file. A Y response will return the menu, allowing the user to make the necessary changes for the next run. If an N or a <cr> response is given, the user is asked if a new control file is desired. A Y response will return the user to entering the file name of the control file and the destination of the printed output; an N or a <cr> response terminates the run.

For every execution of FIBER, a file designed for a printer is created. This file consists of 132 characters per line plus a carriage control character and can be sent directly to a printer or stored in a disk file to be printed later. A summary of the control information is printed first, then the initial stand table, stand tables at the specified intervals, final stand tables, and the yields. For every thinning that occurs, a prethin stand table, the thinning criteria, a postthin stand table, and the yield from this thinning are written. The stand tables in this printer file are more detailed than the ones shown in Table 4. These stand tables show basal area, volume, and board-foot values by species and diameter class.

Beginning users may find it helpful to complete the sample worksheet before running the program (Table 5). This form contains the questions in the order that they will be prompted by the program for the answers. Values do not have to be given for species categories that are not selected at the beginning of projection.

Model Limits

The model predicts well within the range of the data sets for managed stands. However, for some combinations of IBA, RBA, and proportion of hardwoods the equations predict unlikely values of a, b, or c when required to predict growth outside the development data sets at very high densities. Since a_{it}, b_{it}, c_{it}, and m_{it} are probabilities, their true values are non-negative. At high densities, the predicted a-, b-, c-, or m- values might be negative, in which case, the value is set equal to zero and the values were standardized to sum to 1.

Due to insufficient data for mature unmanaged stands over a long time period, constraints were placed on the model to prevent the predictions from becoming unreasonable values. After the stand basal area reaches 15 square feet over the A line on the stocking charts, (Figs. 1–3), the c-value is linearly reduced from the predicted equation value to zero before the stand grows to 20 square feet over the A line. This reduction in the c-value is added to m. Similarly, if the stand should grow to more than 20 square feet over the A line, then the b-value also is linearly reduced to zero before the stand grows to 40 square feet over the A line. Half of the amount removed from the b-value also is added to m with the other half added to the a-value. These two procedures force the projected stand to return below the A line in the stocking charts.

Since the ingrowth equations were developed in managed stands, the ingrowth equations for unmanaged stands had to be modified as the RBA increased beyond the range of the original data (Table 6). When the residual basal area was more than the first number of the range, the predicted ingrowth value was linearly reduced to zero by the second value in the range given. For most species groups, the predicted value went to zero before reaching these constraints. However, these constraints are still in the model should different ingrowth equations be implemented.

These limitations are governed by forest type, which can change over time depending on composition and site index unless the user specified a forest type. The rules for changing the forest type are presented in Table 7. If the conditions stated are not met, the forest type remains the same.

Since all of the development data plots were greater than 20 ft^2/acre (4.6 m^2/ha), the model is programmed to terminate if a stand goes below this density level during a projection. This limitation prevents the acquisition of possible erroneous information and does not appear to impose a restriction on the usefulness of the model.

Conclusion

A two-stage stand projection model, FIBER, has been developed to predict the growth and yields for spruce-fir, northern hardwood, and mixtures of these forest types in the Northeast. It is a matrix model using linear equations to predict ingrowth, the probability of survivor growth, and the probability of mortality by species. The model incorporates transition probabilities, that change over time, to project future diameter distributions and to predict volumes. The model can be applied to managed and unmanaged stands, both even-aged and multi-aged, over a range of densities, site indices, species mixtures, and treatment intervals. A variety of thinning options are possible, including thinning by diameter class. Both thinning and harvest yields are presented. Volume tables are in separate files and can be modified easily for local conditions. The model has been designed for use by researchers, educational institutions, and forest managers of both small woodlots and large forested land areas.

An attempt has been made to make FIBER as "user friendly" as possible. The model is written in Fortran 77, requires 256K, and has been tested on the following computers:

Mainframe: IBM 4341

Operating System: VM/CMS

Availability: Magnetic Tape; EBCDIC, 9-track Electronic Transfer via BITNET

Micros:

IBM PC and compatables

Operating system: MS-DOS 2.0

Availability: 5 1/4 floppy disk

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Table 1.—Regression coefficients for equations used to predict the a-, b-, c-values and ingrowth in the stand projection matrices

Species	Dependent variable	Independent variable[a]							
		Intercept	IBA	RBA	D	P	D^2	RBA^2	PS
Fir	a	.2120	.00274	.00107	.0163	−.1784	−.00134	−.0000110	—
	b	.5851	−.00388	.00071	.0089	.1231	−.00051	.0000082	—
	c	.0368	.00012	−.00089	.0038	.0284	−.00016	.0000026	—
	k	10.9188	—	−.01367	—	−9.0919	—	—	24.9297
Spruce	a	.5841	.00047	.00069	−.0276	−.0709	.00091	−.0000017	—
	b	.2981	−.00100	.00043	.0407	.0152	−.00157	−.0000009	—
	c	.0184	.00030	−.00056	−.0005	.0207	.00011	.0000008	—
	k	3.7023	—	−.02406	—	−2.8019	—	—	−23.9716
Hemlock	a	.4832	−.00069	.00336	−.0515	−.2678	.00173	.0000024	—
	b	.3808	.00030	−.00091	.0554	.2030	−.00198	−.0000109	—
	c	.0865	.00015	−.00157	−.0008	.0483	.00008	.0000056	—
	k	2.1978	—	−.01177	—	.7598	—	—	7.5607
Cedar	a	.5859	.00084	.00084	−.0005	−.1013	.00021	−.0000053	—
	b	.3528	−.00152	−.00017	.0076	.0412	−.00054	.0000052	—
	c	.0159	.00050	−.00068	−.0022	.0546	.00014	.0000007	—
	k	−.5786	—	.01253	—	.0790	—	—	5.9740
Other softwood	a	.7094	.00066	.00052	.0049	−.0190	−.00259	.0000020	—
	b	.1521	−.00095	.00072	.0163	−.0229	.00102	−.0000065	—
	c	.0468	.00009	−.00061	−.0088	.0272	.00083	.0000025	—
	k	1.1028	—	−.00697	—	−.1562	—	—	1.3388
Sugar maple	a	.0558	.00084	.00609	−.0287	.0959	.00109	−.0000242	—
	b	.5776	−.00325	.00061	.0384	−.0484	−.00151	.0000042	—
	c	.2109	.00141	−.00461	.0015	−.0074	−.00003	.0000132	—
	k	2.6186	—	−.02633	—	2.1191	—	—	5.8985
Red maple	a	.3373	.00038	.00409	−.0127	−.0821	.00013	−.0000125	—
	b	.4092	−.00076	−.00182	.0379	.0827	−.00155	.0000041	—
	c	.0984	.00017	−.00129	−.0069	.0079	.00053	.0000044	—
	k	1.8908	—	−.00826	—	.2620	—	—	11.3853
Yellow birch	a	.3290	.00308	.00117	−.0143	−.1577	.00076	−.0000083	—
	b	.4479	−.00466	.00365	.0166	.1598	−.00101	−.0000070	—
	c	.1216	.00094	−.00273	−.0031	.0057	.00017	.0000084	—
	k	1.3759	—	−.00777	—	.5803	—	—	2.2950
Paper birch	a	.4148	−.00069	.00446	.0111	−.1206	−.00009	−.0000129	—
	b	.3944	−.00080	−.00131	.0031	.1560	−.00079	.0000045	—
	c	.0655	.00076	−.00149	−.0060	−.0034	.00044	.0000036	—
	k	1.9167	—	−.01243	—	1.2839	—	—	7.6810
Beech	a	.3343	−.00208	.00743	−.0413	.0006	.00194	−.0000202	—
	b	.3914	.00225	−.00488	.0474	.0877	−.00259	.0000070	—
	c	.1726	.00040	−.00292	.0014	−.0565	−.00005	.0000123	—
	k	2.3648	—	−.02853	—	2.8110	—	—	7.4906

Table 1.—Cont.

Species	Dependent variable	Independent variable[a]							
		Intercept	IBA	RBA	D	P	D^2	RBA^2	PS
White ash	a	.9332	.00054	−.00917	−.0427	−.0114	.00152	.0000427	—
	b	−.5138	−.00199	.01801	.0211	.2982	−.00121	−.0000789	—
	c	.2608	.00038	−.00443	.0210	−.1331	−.00049	.0000181	—
	k	2.7543	—	−.01308	—	.1310	—	—	−4.4739
Aspen	a	.2687	−.00050	.00366	−.0093	−.0363	−.00013	−.0000072	—
	b	.4028	−.00533	.00318	.0320	.1088	−.00118	.0000037	—
	c	.1197	.00292	−.00401	−.0005	−.0462	.00031	.0000036	—
	k	2.8556	—	−.03879	—	−2.2737	—	—	17.3895
Other hardwoods	a	−.3593	−.01269	.01764	.1698	−.1392	−.00899	−.0000158	—
	b	.4994	.01311	−.01439	−.0594	.0839	.00367	.0000022	—
	c	.0683	.00154	−.00266	.0010	−.0302	.00040	.0000051	—
	k	2.4589	—	−.01641	—	1.6005	—	—	1.2478

[a]IBA = initial basal area; RBA = residual basal area; D = diameter class; P = proportion hardwood composition; PS = proportion of species in the composition.

Table 2.—Linear reductions of transition probabilities a, b, and c within the range of maximum diameter classes for trees in stands with more than 125 ft^2/acre

Transition probability	D.b.h. class	Species
	Inches	
c	15–20	All species
b	15–25	Balsam fir, paper birch, aspen, other hardwoods
	20–30	All other species
a	20–30	All species

Table 3.—Actual and predicted average stand volume (ft^3/acre) after 15 years, by species, residual basal-area class, and forest type

Residual basal area (ft^2/acre)	Yield	Species[a]														Percent error
		BF	SP	HE	CE	OS	SM	RM	YB	PB	BE	WA	AS	OH	Total	
							SOFTWOOD									
40(n = 94)	Initial	286	270	9	152	10	2	19	22	19	1	0	4	1	796	
	Actual	667	596	24	179	16	7	31	34	35	2	0	8	4	1605	8.7
	Predicted	605	529	19	182	14	6	36	31	30	2	0	9	2	1465	
80(n = 191)	Initial	545	662	21	218	38	9	38	51	34	4	1	17	9	1648	
	Actual	899	1069	31	251	51	12	60	57	47	6	1	16	11	2511	3.2
	Predicted	833	1051	33	252	46	13	60	61	45	5	1	20	11	2430	
120(n = 135)	Initial	864	866	59	377	44	31	70	103	88	5	0	20	5	2532	
	Actual	1128	1193	70	405	49	29	100	98	94	4	1	22	2	3195	1.3
	Predicted	1092	1186	73	417	25	35	94	106	97	6	0	17	6	3155	
160(n = 29)	Initial	727	1035	40	1148	69	1	72	63	75	6	0	57	2	3295	
	Actual	759	1245	54	1232	67	2	95	39	71	0	0	52	3	3618	– 3.0
	Predicted	853	1288	54	1234	26	2	85	62	71	5	0	45	3	3727	
							MIXEDWOOD									
40(n = 54)	Initial	184	139	10	40	2	88	89	159	69	66	4	26	19	896	
	Actual	486	338	21	59	4	167	143	203	113	88	9	28	29	1689	14.1
	Predicted	363	259	22	52	3	148	151	193	102	96	5	37	20	1452	
80(n = 74)	Initial	390	289	32	77	1	249	163	317	60	114	4	27	24	1748	
	Actual	751	457	59	88	1	348	227	363	82	132	5	34	27	2574	8.8
	Predicted	586	428	53	89	1	333	231	350	75	138	5	30	30	2348	
120(n = 45)	Intial	670	489	45	46	32	243	228	352	129	143	7	256	34	2674	
	Actual	757	676	53	65	38	273	250	347	140	139	11	229	24	3004	– 5.4
	Predicted	839	641	61	57	29	263	294	349	157	156	12	269	39	3167	
160(n = 6)	Initial	454	618	320	289	0	561	107	266	143	194	28	439	50	3469	
	Actual	718	827	343	327	0	423	133	255	169	82	34	434	37	3787	12.9
	Predicted	569	769	238	235	0	402	129	219	132	188	34	331	53	3299	
							HARDWOOD									
40(n = 59)	Initial	42	27	3	0	0	215	92	227	75	184	9	31	4	909	
	Actual	146	78	5	0	0	400	192	339	126	261	16	52	6	1620	12.9
	Predicted	96	51	10	0	0	358	159	296	118	249	14	49	11	1411	
80(n = 69)	Initial	62	51	7	4	0	541	177	383	39	535	23	29	6	1858	
	Actual	113	82	12	3	0	774	230	417	58	561	34	34	10	2326	– 0.8
	Predicted	96	73	11	4	0	736	252	438	52	607	33	34	10	2346	
120(n = 20)	Initial	104	39	21	1	0	1077	72	406	14	942	77	0	16	2769	
	Actual	128	68	23	2	0	1004	99	430	10	984	90	0	7	2846	– 6.7
	Predicted	147	55	32	2	0	1136	97	434	16	1006	95	0	16	3036	

[a]BF = balsam fir; SP = spruce; HE = eastern hemlock; CE = northern white-cedar; OS = other softwoods; SM = sugar maple; RM = red maple; YB = yellow birch; PB = paper birch; BE = American beech; WA = white ash; AS = aspen; OH = other hardwoods

Table 4.—Input/output for a hardwood stand thinned to 40 ft²/acre and then projected for 50 years (Items in italics are entered by the user)

FIBER
Version 2.0

Please choose the output device <1> printer (2) diskfile
2
Please enter the disk file name:
FIBER.PRT
Please enter control file name:
SAMPLE.CTL
Is control file <1> old (2) new?
2

Choose one of the following:

(1)	HELP	(7)	SITE INDEX
(2)	NEW FILE	(8)	PERCENT CULL
(3)	TITLE	(9)	THINNING
(4)	GROWTH PERIOD	(10)	DISPLAY CONTROL
(5)	STOCKING	(11)	DISPLAY STAND
(6)	STAND AGE	<12>	EXECUTE

2
Enter title:
HARDWOOD STAND THINNED THEN ALLOWED TO GROW FOR 50 YEARS
Choose one stocking choice:
(1) Input a tree list.
(2) Input % stocking by dbh class.
<3> Input several plots to be averaged.
1

Please specify which species are to be included in the treelist
Enter a 1 for those to be included, a 0 for those not to be included.

BF	SP	HE	CE	OS	SM	RM	YB	PB	BE	WA	AS	OH
0	*1*	*1*	*0*	*0*	*0*	*1*	*1*	*1*	*1*	*0*	*0*	*0*

entering a <cr> will make whole line 0
First line is diameter classes 5–17, second is 18–30
Please enter the number of trees in each of the 5–17 inch classes for SPRUCE (13 values)
0 0 0 3 0 0 0 0 3 0 0 0 0
Please enter the number of trees in the remaining classes 18–30 for SPRUCE (13 values)
<cr>
Please enter the number of trees in each of the 5–17 inch classes for HEMLOCK (13 VALUES)
6 6 0 3 0 0 0 0 0 0 0 0 0
Please enter the number of trees in the remaining classes 18–30 for HEMLOCK (13 values)
<cr>
Please enter the number of trees in each of the 5–17 inch classes for RED MAPLE (13 values)
3 3 6 0 0 3 0 0 3 0 0 0 0
Please enter the number of trees in the remaining classes 18–30 for RED MAPLE (13 values)
<cr>
Please enter the number of trees in each of the 5–17 inch classes for YELLOW BIRCH (13 values)
6 0 3 3 6 9 0 0 0 0 0 0 0
Please enter the number of trees in the remaining classes 18–30 for YELLOW BIRCH (13 values)
<cr>
Please enter the number of trees in each of the 5–17 inch classes for PAPER BIRCH (13 values)
0 0 6 6 3 6 15 3 6
Please enter the number of trees in the remaining classes 18–30 for PAPER BIRCH (13 values)
<cr>
Please enter the number of trees in each of the 5–17 inch classes for BEECH (13 values)
18 21 15 12 6 0 3 0 0 0 0 3
Please enter the number of trees in the remaining classes 18–30 for BEECH (13 values)
<cr>

HARDWOOD STAND THINNED THEN ALLOWED TO GROW FOR FIFTY YEARS.
INITIAL STAND CONDITIONS Stand age: 0

DIAMETER CLASSES

	5	6	7	8	9	10	11	12	13–15	16–19	20+	TOTAL	SQ. FT.	CU.FT.
SP	0	0	0	3	0	0	0	0	3	0	0	6	3.81	91.5
HE	6	6	0	3	0	0	0	0	0	0	0	15	3.04	37.8
RM	3	3	6	0	0	3	0	0	3	0	0	18	7.00	148.8
YB	6	0	3	3	6	9	0	0	0	0	0	27	10.23	203.4
PB	0	0	6	6	3	6	15	3	6	0	0	45	26.08	677.4
BE	18	21	15	12	6	0	3	0	0	3	0	78	23.59	468.3
TOT	33	30	30	27	15	18	18	3	12	3	0	189	73.76	1627.2

Mean stand diameter = 8.46

Table 4.—Cont.

<cr> to continue
<cr>
Do you want to change initial stand?
N
Please enter the report interval in years <10>:
20
Projection length (years)?
50
Harvest diameter <30>?
<cr>
Will you be growing this stand:
(1) under management?
<2> unmanaged?
1
Is stand (1) even-aged or <2> multi-aged?
<cr>
Enter the approximate age of the stand or
the number of years since major harvest.
(If unknown then enter <cr>)
<cr>
Is the stand on a (1) softwood site (2) hardwood site
or <3> unknown?
2
Enter in the site index for your hardwood stand
(40–80, <60>)
<cr>
Enter the percent cull for each species
SP HE RM YB PB BE
5 5 5 10 10 5
Will you specify thinning levels in (1) basal area,
or in <2> cubic feet?
1
Do you wish to thin on a (1) time interval or
at a <2> stocking level?
1
Enter in the time interval
0
Do you want to control each thinning interactively?
(1) INTERACTIVE
<2> BATCH
1

Choose one of the following:

(1) HELP	(7) SITE INDEX
(2) NEW CONTROL	(8) PERCENT CULL
(3) TITLE	(9) THINNING
(4) GROWTH PERIOD	(10) DISPLAY CONTROL
(5) STOCKING	(11) DISPLAY STAND
(6) STAND AGE	<12> EXECUTE

<cr>

Executing. . .

HARDWOOD STAND THINNED THEN ALLOWED TO GROW FOR FIFTY YEARS.
PRE-THINNING STAND CONDITIONS 0th YEAR Stand age: 0

DIAMETER CLASSES

	5	6	7	8	9	10	11	12	13–15	16–19	20+	TOTAL	SQ. FT.	CU.FT.
SP	0	0	0	3	0	0	0	0	3	0	0	6	3.81	91.5
HE	6	6	0	3	0	0	0	0	0	0	0	15	3.04	37.8
RM	3	3	6	0	0	3	0	0	3	0	0	18	7.00	148.8
YB	6	0	3	3	6	9	0	0	0	0	0	27	10.23	203.4
PB	0	0	6	6	3	6	15	3	6	0	0	45	26.08	677.4
BE	18	21	15	12	6	0	3	0	0	3	0	78	23.59	468.3
TOT	33	30	30	27	15	18	18	3	12	3	0	189	73.76	1627.2

Mean stand diameter = 8.46 q-value = 1.4 (2-inch q-value = 1.8)

<cr> to continue
<cr>

Please choose a type of thinning:

(1) Thin from above	(4) Thin along q-line
(2) Thin from below	(5) Thin by diameter class
(3) Thin uniformly	<6> No thinning

1
Enter the diameter class to start thinning <30>
20

Table 4.—Cont.

Enter the total amount to retain:
40
Please enter the percentage to thin for each species

SP	HE	RM	YB	PB	BE
10	*10*	*10*	*20*	*20*	*30*

Enter thinning priority for each species (1 to 9)

SP	*HE*	*RM*	*YB*	*PB*	*BE*
9	*9*	*7*	*5*	*5*	*3*

Thinning. . .

HARDWOOD STAND THINNED THEN ALLOWED TO GROW FOR FIFTY YEARS.
POST-THINNING STAND CONDITIONS 0th YEAR Stand age: 0

	DIAMETER CLASSES													
	5	6	7	8	9	10	11	12	13–15	16–19	20+	TOTAL	SQ. FT.	CU.FT.
SP	0	0	0	0	0	0	0	0	0	0	0	0	.00	.0
HE	0	0	0	0	0	0	0	0	0	0	0	0	.00	.0
RM	3	3	6	0	0	1	0	0	0	0	0	13	3.15	56.7
YB	6	0	3	3	1	0	0	0	0	0	0	13	3.11	52.6
PB	0	0	6	6	3	6	15	1	0	0	0	37	18.98	486.6
BE	18	21	15	8	0	0	0	0	0	0	0	62	13.38	225.9
TOT	27	24	30	17	4	7	15	1	0	0	0	125	38.61	821.8

Mean stand diameter = 7.53 q-value = 1.5 (2-inch q-value = 2.1)

<cr> to continue
<cr>
Do you wish to:
(1) thin on a time interval <2> at a stocking level
(3) return to pre-thin (4) no more thinning
4

Growing. . .

HARDWOOD STAND THINNED THEN ALLOWED TO GROW FOR FIFTY YEARS.
FINAL STAND CONDITIONS 50th YEAR Stand age: 50

	DIAMETER CLASSES													
	5	6	7	8	9	10	11	12	13–15	16–19	20+	TOTAL	SQ. FT.	CU.FT.
SP	0	0	0	0	0	0	0	0	0	0	0	0	.00	.0
HE	3	3	2	2	2	2	2	2	2	0	0	21	9.41	158.6
RM	5	5	4	3	3	3	2	2	4	1	0	32	15.49	344.5
YB	2	2	2	2	2	2	2	2	4	1	0	21	11.41	240.3
PB	11	11	10	8	6	4	4	4	15	5	0	77	42.49	1044.8
BE	9	9	9	8	8	8	8	8	14	1	0	82	43.26	1006.9
TOT	30	30	27	24	21	19	19	18	38	7	0	233	122.06	2795.1

Mean stand diameter = 9.80 q-value = 1.4 (2-inch q-value = 1.6)

Table 4.—Cont.

<cr> to continue
<cr>
Do you wnat to see the yields for this run?
Y

HARDWOOD STAND THINNED THEN ALLOWED TO GROW FOR FIFTY YEARS

Standing yield

	PULPWOOD		SAWTIMBER		
	B.A.	CU.FT.	B.A.	CU.FT.	BOARD FEET
SPRUCE	.0	.0	.0	.0	.0
HEMLOCK	2.0	26.4	7.4	132.2	851.3
RED MAPLE	5.7	107.7	9.8	236.8	1142.3
YELLOW BIRCH	3.9	73.1	7.5	167.3	890.6
PAPER BIRCH	14.6	323.1	27.9	721.8	4039.6
BEECH	13.2	262.7	30.0	744.2	3561.3
TOTAL	39.4	792.9	82.7	2002.2	10485.1

<cr> to continue
<cr>

Total yield from thinnings

	PULPWOOD		SAWTIMBER		
	B.A.	CU.FT.	B.A.	CU.FT.	BOARD FEET
SPRUCE	.2	4.6	3.6	86.9	432.0
HEMLOCK	2.0	23.5	1.0	14.3	.0
RED MAPLE	.2	4.6	3.7	87.5	357.0
YELLOW BIRCH	2.7	56.0	4.4	94.8	.0
PAPER BIRCH	.7	19.1	6.4	171.7	954.0
BEECH	4.4	97.1	5.9	145.3	852.0
TOTAL	10.2	204.9	24.9	600.5	2595.0

<cr> to continue
<cr>

Total yield

	PULPWOOD		SAWTIMBER		
	B.A.	CU.FT.	B.A.	CU.FT.	BOARD FEET
SPRUCE	.2	4.6	3.6	86.9	432.0
HEMLOCK	4.0	49.9	8.4	146.4	851.3
RED MAPLE	5.9	112.3	13.5	324.3	1499.3
YELLOW BIRCH	6.6	129.1	11.9	262.0	890.6
PAPER BIRCH	15.3	342.1	34.3	893.5	4993.6
BEECH	17.6	359.7	35.9	889.6	4413.3
TOTAL	49.6	997.8	107.6	2602.7	13080.1

Do you want another run on this control file?
N
Do you want to use another control file?
<cr>
Stop - Program terminated

Table 5.—FIBER worksheet

OUTPUT: <1> PRINTER (2) DISKFILE: _____
CONTROL FILE: _____ <1> OLD (2) NEW
TITLE: _____
SPECIES
CHOICE: BF SP HE CE OS SM RM YB PB BE WA AS OH
_ _ _ _ _ _ _ _ _ _ _ _ _ _
INPUT CHOICE: a) DIAMETER LIST BY SPECIES
b) # STEMS BY SPECIES AND % IN DIAMETER CLASS
c) PRISM PLOTS OR FIXED PLOTS
(1) BAF OR INVERSE OF PLOT SIZE
(2) 1- or 2-INCH CLASSES
REPORT INTERVAL (5,10,15. . . .):
PROJECTION LENGTH:
HARVEST DIAMETER:
MANAGED OR UNMANAGED:
STAND STRUCTURE: (1) EVEN-AGED
<2> MULTI-AGED
STAND AGE:
FOREST TYPE: (1) SPRUCE-FIR (2) NORTHERN HARDWOODS <3> UNKNOWN
SITE INDEX:
BF SP HE CE OS SM RM YB PB BE WA AS OH
PERCENT
CULL: _ _ _ _ _ _ _ _ _ _ _ _ _ _
THINNING SPECIFICATIONS: (1) SQUARE FEET
<2> CUBIC FEET
WHEN TO THIN: (1) YEARS TO RUN PRIOR TO THIN _____
<2> STAND DENSITY LEVEL _____

INTERACTIVE _____ , BATCH _____
SILVICULTURAL TREATMENT:
ABOVE _____ q-LINE _____
BELOW _____ DIAMETER CLASS _____
UNIFORM _____ NONE _____
MAXIMUM DIAMETER CLASS FOR q-LINE _____
STARTING DIAMETER CLASS FOR ABOVE, BELOW
THINNING LEVEL TO RETAIN: (1) BA _____ VOL _____
(2) B-LINE FOR EVEN-AGED STANDS
BF SP HE CE OS SM RM YB PB BE WA AS OH
PERCENT
THINNED: _ _ _ _ _ _ _ _ _ _ _ _ _ _
PRIORITY
LIST (1–9): _ _ _ _ _ _ _ _ _ _ _ _ _ _

Table 6.—Basal-area range, by forest type and species, at which ingrowth is forced to zero

Species	Softwood	Mixedwood	Hardwood
		ft^2/acre	
Fir	190–220	160–190	110–140
Spruce	190–220	130–160	110–140
Cedar	190–220	130–160	110–140
Aspen	80–110	80–110	80–110
All other	150–180	130–160	110–140

Table 7.—Criteria for allowing a change in forest type

Current forest type	Condition	New forest type
Softwood	Site index for softwood ≥50 for hardwood composition ≥50%	Mixedwood
Mixedwood	Site index for softwood ≤50 and hardwood composition ≤35%	Softwood
	Site index for hardwood ≥60 for hardwood composition ≥75%	Hardwood
Hardwood	Site index for hardwood ≤60 and hardwood composition <50%	Mixedwood

Solomon, Dale S.; Hosmer, Richard A.; Hayslett, Homer T., Jr. 1987 **FIBER handbook: a growth model for spruce-fir and northern hardwood types.** NE–RP–602. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 19 p.

A matrix model, FIBER, has been developed to provide the forest manager with a means of simulating the management and growth of forest stands in the Northeast. Instructional material is presented for the management of even-aged and multi-aged spruce-fir, mixedwood, and northern hardwood stands. FIBER allows the user to simulate a range of silvicultural treatments for a variety of species compositions growing on different sites. The internal structure of the model is defined and explanations on the use of FIBER are offered. Examples of input, interim procedures, and final output are shown.

ODC: 562.2:564:228.3

Keywords: Growth; model; mixed species; spruce; northern hardwoods

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**Northeastern Forest
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Silvicultural Guide for Northern Hardwood Types in the Northeast (revised)

William B. Leak
Dale S. Solomon
Paul S. DeBald

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Abstract

A revision of the 1969 silvicultural guide for northern hardwoods, provides up-to-date information on both even-age and uneven-age silviculture and management for beech-birch-maple, beech-red maple, and mixedwood stands in the Northeast.

The Authors

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COVER—Many-aged northern hardwood stand after improvement cutting, Bartlett Experimental Forest

Purpose and Scope

This is the third silvicultural guide for northern hardwoods (beech-birch-maple) in the Northeast. The first, published in 1958 (Gilbert and Jensen 1958), provided general guidelines on initial cutting methods in uneven-aged old-growth stands and even-aged second-growth stands. The second, published in 1969 (Leak et al. 1969), provided quantitative information on stocking and yield as well as a key to specific stand presecriptions, particularly for even-age management. This revised guide includes new information on forest types, site, stocking, growth and yield, and regeneration methods, including shelterwood and group selection.

The information in this guide applies to about 20 million acres of northern hardwood and mixed hardwood-conifer types across New England and New York. Outside this area, the guide should be applied with caution. The guide is primarily concerned with timber production. A guide to the management of wildlife habitat in hardwood and conifer types in New England is in preparation.

Regional Conditions

Northern hardwoods and associated species are used for a variety of products, including veneer, sawlogs, boltwood, pulpwood, fuelwood, and miscellaneous products such as posts. In New England, sawlogs and veneer presently account for about one-quarter of the hardwood harvest, and pulpwood accounts for about one-half. In states such as New Hampshire, fuelwood currently accounts for a significant proportion of the hardwood cut. In many areas, markets for low-quality material provide opportunities for improving the northern hardwood forest without heavy investments in noncommercial silvicultural work. Also, substantial increases in land and timber prices over the last 10 to 15 years have strengthened timberland investments. Indications are that current trends will continue upward, though perhaps at a lower rate.

Many timberland owners in New England own land primarily for reasons other than growing timber. In New Hampshire and Vermont, only 6 percent of the owners, controlling 21 percent of the timberland, listed wood production as one of the important reasons for ownership (Kingsley and Birch 1977). Foresters must consider the other values of timberland—recreation, esthetics, buffers, wildlife, investment, etc.—and be prepared to use silvicultural approaches that will complement or enhance these values.

Species and Sites

Three cover types, or subtypes, are described in this guide: beech-birch-maple (typical northern hardwood), beech-red maple, and mixedwood (hardwoods and associated softwoods). The occurrence of these types usually is related to site conditions—soils, climate, and bedrock mineralogy; in parts of the Northeast, these forest types are known to occur on certain land types, forest habitats, or soil series. Those who manage stands primarily for paper birch, oak, white pine, spruce-fir, or cherry-maple should use the guides written specifically for those types.

The beech-birch-maple type contains sugar maple as the characteristic species in proportions ranging from 15 to 20 percent to nearly 100 percent of the basal area. This type is characteristic of well- to moderately well-drained, fine-textured or loamy till soils. Sugar maple and/or white ash are most abundant on the best soils—for example, those that are enriched with organic matter or derived from limestone. However, on average beech-birch-maple sites, beech may account for up to 50 percent of the basal area. The most common birch species are yellow and paper birches. However, in southern New England, sweet birch and northern red oak (often of good quality) may be common associated species. The successional tendency is toward the tolerant species—beech and sugar maple.

Beech-red maple stands usually occupy poorer sites than beech-birch-maple stands—soils that are more shallow, wetter, or drier than those with typical northern hardwoods. The central characteristic of these hardwood stands is that sugar maple is uncommon and/or slow growing. On dry sites, beech may be the predominant species. On wet sites or shallow soils, red maple often is the most common species. Yellow birch and paper birch (or sweet birch in southern New England) are common associates. Some of these stands originated from heavy cutting of softwood or mixedwood stands. Old stands sometimes show a successional trend toward tolerant softwood types—hemlock and/or red spruce. Or the successional tendency may be toward a predominance of beech. Some of the characteristic soils are productive for red oak; less so for sugar maple, yellow birch, or white ash.

Mixedwood (hardwoods with primarily spruce, hemlock, or balsam-fir) stands have at least three origins: (1) partial or heavy cutting of softwood stands, which allowed hardwood invasion to occur; these stands appear as the beech-red maple cover type with a softwood component or understory; (2) forest succession on abandoned fields, which tends to favor increased proportions of white pine, hemlock, spruce (red or white), or balsam-fir even on good hardwood sites that normally would support the beech-birch-maple type; and (3) diverse site conditions, e.g., shallow or rocky soils interspersed with better soils, which results in groups of hardwoods and softwoods. Because of different origins, successional trends in mixedwood stands may be toward tolerant softwoods, hardwoods, or maintenance of the mixedwood character.

Type	*Distinguishing Factors*
Beech-birch-maple	1. Fifteen percent or more sugar maple in overstory and/or understory. 2. Sugar maple more abundant than red maple. 3. Less than 25 percent softwoods in overstory or understory. 4. Commonly found on well- to moderately well-drained fine-textured till soils.
Beech-red maple	1. Less than 15 percent sugar maple in overstory and understory. 2. Red maple more abundant than sugar maple. 3. Less than 25 percent softwoods in overstory and understory. 4. Commonly found on soils that are wetter, drier, more shallow to bedrock or pan, rockier, or more poorly aerated than those supporting beech-birch-maple stands.
Mixedwood	1. Softwoods (primarily spruce, hemlock, or balsam-fir) account for 25 to about 65 percent of the overstory and/or understory. 2. No specifications on the relative proportions of sugar maple and red maple. 3. Found on a wide variety of soils due to the varied past history and origin of mixed-wood stands.

Note that certain intolerant or intermediate species—paper birch, yellow birch, aspen, etc.—are not indicative of site condition.

Silvicultural opportunities differ for each subtype. The beech-birch-maple type regenerates and produces large, high-quality hardwoods such as sugar maple, yellow birch, or, in some areas, white ash. The beech-red maple type commonly produces smaller, lower grade sawlogs. However, such areas can produce acceptable boltwood stems (birches) or aspen for wildlife; oak sawlogs are a possibility in certain parts of the northern hardwood region. In many mixedwood stands, the possibilities for hardwood products are similar to those for the beech-red maple subtype. Here, volume production can be increased by gradually favoring the softwood component. However, due to the variable origin of mixedwood stands, large high-quality hardwoods can be grown on some sites.

Silvical characteristics of the important species found in these three types are outlined in Table 1. The shade-tolerance categories of tolerant, intermediate, and intolerant indicate whether the species can regenerate and persist under conditions of heavy, moderate, or no shade, respectively. Moderate shade would be about 30 to 70 percent crown cover.

The categories of early height growth indicate the general ability of a species to outgrow its associates up through the sapling stage with no overhead competition. For example, aspen grows very fast and seldom needs release from associated species to maintain a dominant position, and red maple normally is outgrown by aspen and paper birch. Sugar maple and beech are outgrown by most other hardwood species even when free of competition.

The relative site requirements vary by species. White ash, and sugar maple to a slightly lesser extent, are most abundant and reach best development on the best soils. Conversely, spruce, hemlock, and white pine are common and grow to fairly large size on soils that are shallow, rocky, sandy, or wet. Paper birch, red maple and aspen, though fast growers on good sites, can be reproduced and grown fairly successfully on poor sites.

The natural pruning categories refer to a species' relative ability to produce clear boles. The softwoods, as well as sugar maple and beech, only produce clear boles at an early age under conditions of high stand density. However, paper birch, white ash, and aspen produce clear straight boles at only 50 to 60 percent of maximum stand density.

Protection

Diseases and insects are the two important problems. Fire damage and prevention have a minor impact on silvicultural methods in northern hardwoods and related types.

Table 1.—Silvical characteristics of the important species of the three cover types

Species	Shade tolerance	Early relative height growth	Relative site requirements	Natural pruning	No. years between good seed crops	Sprouting vigor	Delayed germination
Sugar maple	Tolerant	Slow to moderate	High	Poor to medium	3–7	Moderate—small stumps	Negligible
American beech	Tolerant	Slow	Medium	Poor	2–5	Low—stump sprouts High—root suckers	None known
Yellow birch	Intermediate	Moderate	Medium to high	Medium	1–3	Low	Seldom
Paper birch	Intolerant	Fast	Medium	Good	2	Moderate—small stumps	None known
White ash	Intermediate (more tolerant as a seedling)	Moderate	High	Good	2–5	Moderate to high	Up to 75 percent
Red maple	Intermediate	Moderate	Low	Medium	1	High	Moderate percentage may germinate 2nd spring
Aspen	Intolerant	Very fast	Low	Good	4–5	High—root suckers	None
Northern red oak	Intermediate	Moderate	Medium	Medium	3–5	High	None
Red spruce	Tolerant	Very slow	Low	Poor	3–8	None	None known
Eastern hemlock	Tolerant	Very slow	Low	Poor	2–4	None	None known
Eastern white pine	Intermediate	Slow to moderate	Low	Poor	3–10	None	None known

Few silviculturalists can develop expertise in entomology or pathology. However, they should be able to: (1) recognize threats to quality and vigor; (2) apply silvicultural and utilization methods that will minimize losses; and (3) know when to seek expert advice on potential outbreaks. Beyond this section, few references will be made to specific insects and diseases. However, many of the silvicultural practices described later relate to potential stand quality and risk.

Microorganisims that cause decayed and discolored wood, one of the most widespread problems in both hardwoods and softwoods, enter through dying or damaged roots, stems, or branch stubs. Other fungi cause collar cracks in birches and root rot and basal decay in many other species. For details on discoloration, decay, and other defects, see Shigo and Larson (1969) and Shigo (1983).

To limit losses in stand volume and quality from decay and discoloration, silvicultural methods should be directed toward (1) removing defective trees during harvest operations, (2) encouraging the development of small limbs and early natural pruning by maintaining fairly high stand densities in sapling and pole stands (or consider artificial pruning), and (3) minimizing logging damage to roots, stems, and branches. Decay and discoloration associated with wounds or branch stubs usually do not enter into wood formed after the wound occurs or after the branch dies.

Nectria cankers are common in many hardwoods, and *Eutypella* canker is found on maples. Associated decay is limited, but wind breakage is common and the cankers often cause quality defects in the most valuable parts of the bole.

Beech-bark disease is the most lethal disease of beech. The beech scale (*Cryptococcus fagi* (Baer)) punctures the bark, allowing a bark-killing fungus (*Nectria coccinea* vac. *faginata*) to enter. Small vigorous trees sometimes survive the disease, though quality may be severely reduced. Large trees seldom survive. Significant tree-to-tree variation is evident in susceptibility to both the scale and the *Nectria* fungus. Trees exhibiting the characteristic red fruiting bodies should be harvested without delay.

The saddled prominent (*Heterocampa guttivitta*) is the most serious defoliator of beech-birch-maple stands. White ash and red maple sometimes escape attack, but most other hardwoods can be heavily defoliated. The outbreaks occur on about a 10-year cycle, and last 1 to 3 years. Defoliation in 2 successive years may be followed by widespread mortality and growth losses, as well as degrade (e.g., stain) from secondary insects and organisms. Aerial chemical sprays have proven effective in limiting damage by the saddled prominent.

Gypsy moth (*Lymantria dispar*) is the most serious defoliator of oak in central to southern New England. Grey birch, aspen, and sometimes other hardwoods are frequently defoliated as well. White pine and hemlock associated with oak stands also are defoliated during severe attacks. Outbreaks generally last 1 to 3 years. Mortality and/or growth loss in oak can be significant after two or more defoliations. There is some indication that degrade from insects (e.g., oak borer) may increase in trees weakened by defoliation. Insecticidal and biololgical aerial sprays are effective.

Larval galleries of the sugar maple borer (*Glycobius speciosus*) result in partial girdles and cankers that allow the development of decay and discoloration and increase susceptibility to wind breakage. Up to 50 to 60 percent of the sugar maple in a stand may be affected, with an average of two to three significant cankers per tree. Contrary to earlier recommendations, exposure of trees by cutting apparently does not increase susceptibility to damage by the sugar maple borer.

Management Objectives and Approaches

In developing a long-range timber management objective for an entire forest property, the owner or manager should first decide on product and species goals. A common product objective is high-quality material for veneer logs, sawlogs, and boltwood combined with utilization of the poorer quality material for pulp or fuelwood. A second objective on certain industrial lands or private ownerships might be maximum production of wood for fiber and/or fuel. Other product objectives include high-intensity management for veneer logs, or production of small logs and boltwood. The choice of species or species group is closely related to the desired product, and is concerned with what species to favor in improving and regenerating the stand.

Two primary factors affecting the choice of product and species are (1) current and projected markets, and (2) the capability of the land to grow certain products and species. Once the product and species objectives are set, a preliminary decision can be made on appropriate silvicultural systems for the property. For tolerant species and high-quality products, one standard approach in the Northeast has been uneven-age management using individual-tree selection or some form of partial cutting. For quality products from intolerant and intermediate species, a common approach is even-age management using clearcutting and intermediate treatments. Even-age management with clearcutting is best suited to the mechanized production of fiber or fuel.

Table 2.—Species of regeneration favored (not exclusively) by certain harvesting methods in three cover types

Type	Individual tree-selection	Group selection	Dense shelterwood[a]	Open shelterwood[b]	Clearcut
Beech-birch-maple	Sugar maple Beech	Birches	Sugar maple Beech	Yellow birch	Birches
Beech-red maple	Beech Red maple	Red maple Birches	Beech Red maple	Red maple Yellow birch	Birches
Mixedwood	Tolerant softwoods or hardwoods	Red maple Birches	Hemlock Spruce Tolerant hardwoods	Red maple Birches	Birches

[a]Residual crown cover of about 80 percent.
[b]Residual crown cover of 30 to 50 percent (occasionally up to 70 percent).

However, in assessing each stand, additional factors must be considered in reaching a decision on the immediate silvicultural techniques. Either an uneven-age or even-age approach can be used to grow most species groups or products: uneven-age management with group selection can ensure a good mix of intermediate and some intolerant species; even-age management with shelterwood cutting can be designed to encourage a high proportion of tolerants (Table 2). And rotation age, stocking, stand structure, and logging equipment can be varied to meet various product objectives.

One of the important additional factors to consider is current stand condition. For example: high-risk stands may need to be regenerated by clearcutting or shelterwood to prevent large volume losses; or clearcutting a stand with a wide range in tree diameter may remove a high proportion of financially or biologically immature trees.

Another factor is accessibility. With high costs for road construction, some form of heavy cutting may be the only economically feasible regeneration harvesting method on the first entry. Esthetic and wildlife objectives also should be considered in choosing a silvicultural system. And in special circumstances, the possibility of site and/or stand deterioration needs to be assessed. For example, clearcutting on very poorly drained soils without adequate advance regeneration or in potential frost pockets may result in an overabundance of herbaceous or shrubby vegetation.

Uneven-Age Management

Harvesting Methods

Uneven-age management is implemented by individual-tree selection and group selection. Individual-tree selection removes trees one by one to maintain a fairly uniform and continuous crown cover appropriate for regenerating tolerant species. Group selection is the removal of trees in groups roughly 1/20 to 2 acres in size. It is especially appropriate where: (1) the objective is to maintain up to one-half of the regeneration in intolerant or intermediate species, and (2) the overstory contains groups of poor-risk, defective, or overmature trees. Group selection generally is applied in combination with individual-tree marking between the groups.

Group selection may be applied in two ways: groups of overstory trees can be removed, leaving a desirable stand of seedlings, saplings, or small poles; or entire groups of trees down to 2-inches d.b.h can be removed. The latter approach is used to eliminate undesirable sapings and small poles, resulting in a maximum proportion of intolerant or intermediate regeneration.

Growth and Yield

Results from a study of residual basal area and structure in a second-growth, beech-red maple stand illustrate the typical responses of hardwood stands in New England to density and structure (Table 3). Basal-area and cubic-foot

Table 3.—Net annual growth per acre over a 9-year period of sawtimber (10.5 inches plus) and total stand (4.5 inches plus), by residual basal area and amount of sawtimber in a second-growth beech-red-maple stand (approximate site index 55 for sugar maple) (Solomon 1977)

Residual basal area (ft^2)	Residual sawtimber		Net growth				Accretion	
	Percent	Basal area	Sawtimber[a]		Total		Sawtimber[b]	
			Square feet	Board feet	Square feet	Cubic feet	Square feet	Board feet
40	30	12	1.4	126	2.2	53	.51	46
	45	18	1.3	117	2.0	48	.68	61
	60	24	0.5	45	1.8	43	.69	62
60	30	18	1.3	117	1.7	41	.55	50
	45	27	1.7	153	2.3	55	.76	68
	60	36	1.6	144	2.0	48	.88	79
80	30	24	2.0	180	1.7	41	.64	58
	45	36	1.6	144	1.7	41	.71	64
	60	48	1.0	90	1.2	29	.92	83
100	30	30	1.9	171	1.7	41	.70	63
	45	45	1.6	144	1.2	29	.88	79
	60	60	1.1	99	0.9	22	1.07	96

[a]Includes only the sawtimber portion of the stem.
[b]Based on conversions of 90 board feet and 24 ft^3 per square foot of basal area.

growth generally are best between 40 and 60 ft^2 of residual basal area per acre. Board-foot growth, however, is best between 60 and 80 feet of basal area provided that at least 25 to 35 ft^2 of basal area in sawtimber is maintained. With these fairly low sawtimber basal areas, much of the sawtimber growth is ingrowth into the larger sizes rather than accretion. Accretion tends to rise as the basal area in sawtimber approaches 50 to 60 ft^2; however, mortality and lower sawtimber ingrowth reduce the net sawtimber growth. Retention of live branches is noticeable at 60 ft^2 basal area, indicating that timber quality development should be best at residual basal areas of 70 to 80 ft^2.

On better sites, those supporting beech-birch-maple stands, experience indicates that higher amounts of residual sawtimber could be maintained that produce high-quality sawtimber growth.

Stocking and Structure

Recommended minimum residual basal areas in trees 5.0 inches and larger in d.b.h. are:

Type	*Residual Basal Area (ft^2)*
Beech-birch-maple	70 (65–75)
Beech-red maple	70 (65–75)
Mixedwood	100 (80–120)

The mixedwood goal applies to residual stands with 25 to 65 percent softwood in trees 5.0 inches and larger in diameter. A range in basal area is given to encourage flexibility. On good sites, those with an abundance of quality timber, residual basal areas above the suggested range may be specified. However, residual basal areas below the suggested range may impair quality development.

Stand structural goals for uneven-age management are specified by the maximum size tree to leave, and the diameter distribution. Diameter distributions are approximated by a reverse J-shaped curve, with a slope defined by q—the quotient between numbers of trees in successively smaller d.b.h. classes.

The structural goals in this guide are based on a range in q from 1.3 to 1.7, and a maximum tree size (for general planning purposes) of 20 inches d.b.h.:

q	*Approximate percent sawtimber*
1.7	45
1.5	55
1.3	70

We emphasize that the maximum tree size of 20 inches d.b.h. is a very flexible goal. Tree vigor and quality are more important than the specified maximum tree size in deciding which trees to take or leave. On poor sites, tree vigor and quality of some species may decline rapidly at 16 inches d.b.h. or larger; on these sites, low amounts of sawtimber (q = 1.7) are most appropriate. On good sites, trees may easily be grown to 24 inches or larger; on such sites, high proportions of sawtimber (q = 1.5 to 1.3) should be best.

On the basis of these combinations of q and residual basal area, residual structural goals in terms of basal area per acre by diameter class are outlined in Table 4 for both hardwood and mixedwood types. Only three diameter classes are used since this results in easier application and allows for some departure from the strict reverse J-shaped form. Recent information indicates that slightly S-shaped form of diameter distribution may be more natural, productive, and economical.

In choosing a structural goal, it often is reasonable to aim for a q that is about the same as or slightly lower than the existing q before cutting. The q before cutting can be judged quickly by using the tabulation for percent sawtimber. A more precise estimate of the appropriate residual structure can be developed by following the marking guide procedures described in the next section. The structures listed in Table 4 should be used as a guide, and can be attained by feasible and economical cutting practices.

The structural goal of q = 1.7 is appropriate for the first entry in many cutover stands, which often have a low proportion of sawtimber (Fig. 1). However, the initial cut in a previously unmanaged stand may produce an extremely variable diameter distribution. Total residual density, and the removal of poor growing stock, are more important than structure in these early cuts. During subsequent entries, it may be feasible to leave a higher proportion of sawtimber (a lower q). On mediocre sites (e.g. beech/red maple stands), the sawtimber will decline in vigor and growth rate as it becomes larger, so it may never be possible to grow large-size trees or to reduce the q below 1.5 or 1.7. On good sites (e.g., supporting sugar maple/ash) capable of sustaining high proportions of sawtimber (Fig. 2), q's of 1.3 are attainable.

On areas scheduled for maximum production of fiber or fuel, low proportions of sawtimber (a q of 1.7 or higher) should be best.

In poletimber stands with less than about 25 to 30 ft^2 of sawtimber, there is little reason to be concerned about structure. Such stands can be treated by commercial stand improvement measures that remove the poorer quality overstory stems and leave 70 to 80 ft^2 of basal area per acre. In subsequent treatments, as the sawtimber component develops, the use of structural goals will be more appropriate.

Table 4.—Minimum stand structure objectives for residual hardwood (beech-birch-maple and beech-red-maple) and mixedwood stands

D.b.h. class (inches)	q = 1.7		q = 1.5		q = 1.3	
	Hard-wood	Mixed-wood[a]	Hard-wood	Mixed-wood[a]	Hard-wood	Mixed-wood[a]
	Ft^2 of basal area/acre					
6–10	38	54	30	42	21	30
12–14	18	26	20	28	20	28
16+	14	20	20	30	29	42
All	70	100	70	100	70	100

[a]Softwood basal area 25 to 65 percent of total.

Figure 1.—Cutover stand of northern hardwoods with low to moderate proportion of sawtimber. Immediate residual goals in such stands would be 30 to 40 ft^2 of sawtimber or a q or 1.7 to 1.5. A good northern hardwood site with good-quality sugar maple, this area could support more sawtimber (lower q) in the future.

Cutting Cycle

The cutting cycle—the years between harvests on the same area—is determined by accessibility, the need for an economic harvest, timber growth, and quality. Based on an average basal growth rate for northern hardwoods of 2 ft^2/acre/year a residual stand of 70 ft^2 will grow to 100 ft^2—a reasonable maximum—in about 15 years. At that time, a cut of about 30 ft^2 (8 to 9 cords) will be available. With good accessibility, high timber values, or high risk of damage from insects or diseases, the cutting cycle might be lowered to 10 years. Under opposite conditions, cutting cycles of up to 20 years sometimes are used. With long cutting cycles, the total residual basal areas in Table 4 can be lowered to minimums of 60 to 65 ft^2 for hardwood and about 75 to 80 ft^2 for mixedwood, proportioning the reductions among size classes.

Marking Guides

The success of uneven-age management—both silviculturally and economically—depends to a large extent on the choice and application of appropriate marking guides.

Marking guides can be developed from a prism inventory of the stand, classifying the trees by d.b.h. and condition classes:

1. Acceptable Growing Stock: Trees with the potential to produce sawlog or better quality material, now or in the future, and that are in vigorous condition. These can be subdivided into mature (based on biological or financial maturity) and immature. Suggested tree sizes denoting financial maturity are shown in Table 5.

Figure 2.—Northern hardwood stand with a high proportion of fairly good-quality sugar maple. The residual goal in this stand would be about 50 ft^2 of sawtimber or a q of approximately 1.3.

2. Unacceptable Trees: Trees that will not produce sawlog or better material now or in the future *or* trees that are high risk—subject to mortality or rapid losses of merchantable volume or quality before the next harvest. Valuable high-risk trees are especially important to recognize.

3. Cull: Trees with more than 50 percent of their cubic volume in sound or rotten cull; or use a local or agency definition.

Certainly, additional tree condition classes could be developed to meet local timber or wildlife needs. Individual species or species groups often should be tallied to help refine silvicultural objectives and develop marking guides. Prism-plot basal areas, by d.b.h. and tree condition class can be summarized as in the following example:

D.b.h. class (inches)	*Mature*	*Immature*	*Defective*	*High risk*	*Cull*	*Total*
			ft^2 basal area/acre			
6–10	—	40	10	—	—	50
12–14	—	10	10	20	—	40
16+	5	5	5	10	—	25
All	5	55	25	30	—	115

Table 5.—Tree-size objectives (d.b.h.) denoting peak of possible log-grade improvement (financial maturity) for northern hardwoods (high and medium-grade potential reflect the marker's best judgement on tree condition and site potential for that species)

Species	Grade potential[a]	Log section[b]	D.b.h. objective
			Inches
Yellow birch	High	1	18
	High	2	20
	Medium	1	16
	Medium	2	18
Sugar and red maple[c]	High	1	18
	High	2	20
	Medium	1	16
	Medium	2	18
Beech	High	1	16
	High	2	18
	Medium	1	14
	Medium	2	16
Paper birch	High	1	16
	High	2	16
	Medium	1	12
	Medium	2	12
White ash	High	1	18
	High	2	20
	Medium	1	16
	Medium	2	18
Red spruce	Medium or better	Any	14–16
Hemlock	Medium or better	Any	18–20

[a]High-grade potential means that the first 1- or 2-log portion of the stem could produce grade 1 or veneer-grade logs. Medium-grade potential means that the highest quality would be no more than grade 2. Grades are based on USDA Forest Service standard specifications for hardwood factory lumber and veneer logs.

[b]Predominant merchantable height.

[c]In many areas, red maple has medium-quality potential at best, so d.b.h. objectives commonly are 14 to 16 inches.

This hypothetical northern hardwood stand has 57 percent of the basal area in sawtimber. A stand with a q of 1.5 has approximately 55 percent of the basal area in sawtimber, so a structural goal of q = 1.5 would be a reasonable first choice (see tabulation for percent sawtimber). However, in looking at the tree condition classes, a reasonable set of marking guides might be:

1. Remove high-risk timber in the 12- to 14-inch class.

2. Remove high-risk timber in the 16+ class.

3. If a cordwood market were available, remove defective trees in the 6- to 10-inch class

Application of these marking rules would leave a residual stand as follows:

D.b.h. class (inches)	*Mature*	*Immature*	*Defective*	*Total*	*Goal (q = 1.7)*
	– – – – – –ft² of basal area/per acre – – – – – –				
6–10	—	40	—	40	38
12–14	—	10	10	20	18
16+	5	5	5	15	14
All	5	55	15	75	70

This residual stand is close to the structural goal of q = 1.7 in Table 4, and the stand contains a high proportion of vigorous growing stock.

An alternative approach is to follow generalized marking rules related to stand condition (Table 6). With 65 ft^2 of sawtimber, the hypothetical initial stand qualifies as beech-birch-maple large sawtimber. Total initial basal area is more than 100 ft^2, so a cut is warranted using either single-tree or group selection. The suggested residual basal area is 75 ft^2, with 40 to 55 ft^2 of sawtimber. In this example, the use of Table 6 leads us into leaving a little more sawtimber basal area (8 to 23 ft^2 more), and a corresponding smaller amount of poletimber, than is suggested by the prism-plot summary of the actual condition of the growing stock.

Noncommercial Work

Noncommercial stand improvement work is minimal with uneven-age management because each harvest operation provides the opportunity to improve the stand by removing marginal or submarginal trees. However, three types of noncommercial work are possible.

Table 6. Summary of general marking guides

Type	Stand size class	Initial stand: Sawtimber basal area	Initial stand: Total basal area 5.0 inches + [a]	Cutting method	Regeneration favored	Residual stand: Sawtimber basal area	Residual stand: Total basal area 5.0 inches + [a]
		Ft^2				Ft^2	
Beech-birch-maple	Poletimber	30	100 +	Stand Improvement	Sugar maple-beech		65
	Small sawtimber	30–50	100 +	Single-tree	Sugar maple-beech	30–40	70
				Group	Yellow birch-paper birch	30–40	70
	Large sawtimber	50–75	100 +	Single-tree	Sugar maple-beech	40–55	75
				Group	Yellow birch-paper birch	40–55	75
Beech-red-maple	Poletimber	30	100 +	Stand Improvement	Beech-red maple		65
	Small sawtimber	30–50	100 +	Single-tree	Beech-red maple	30–40	70
				Group	Yellow birch-paper birch	30–40	70
	Large sawtimber	50–75	100 +	Single-tree	Beech-red maple	40–55	75
				Group	Yellow birch-paper birch	40–55	75
Mixedwood	Poletimber	50	130 +	Stand Improvement	Tolerant softwoods or hardwoods		80
	Small sawtimber	50–70	130 +	Single-tree	Tolerant softwoods or hardwoods	45–55	100
				Group	Intermediate[c] and intolerant hardwoods	45–55	100
	Large sawtimber	70–90	130 +	Single-tree	Tolerant softwoods or hardwoods	55–75	100–120
				Group	Intermediate[c] and intolerant hardwoods	55–75	100–120

[a]Stands with less basal area than specified should be left to grow.

[b]Group selection normally includes individual-tree selection between groups.

[c]If tolerant or intermediate softwood regeneration is present, group selection can be used to favor these species by group removal of the overstory where the softwood regeneration is well developed.

1. *Cull Removal*: Culls to be removed should be designated during marking. Residual culls should be included in defining the residual basal area and structure—because they influence growth, regeneration, and quality development. Elimination of understory culls is of doubtful value because of their abundance, slow growth, and high mortality. Keep in mind the importance of reserving some cull trees, especially the large ones, for wildlife. More than 30 species of birds and 20 mammals use culls in New England for feeding, nesting, or denning.
2. *Two-Inch Removal*: When group selection is applied, and the saplings or small poles within a group are of undesirable species or quality, complete stem removal down to about 2 inches d.b.h. is recommended. Generally, this is most easily done during the logging operation, though a separate postlogging treatment also is possible using chemical or mechanical methods.
3. *Group Stand Improvement*: Groups of saplings or small poles resulting from previous group-selection cuttings may be dominated by stems of low-quality or undesirable species. If less than about 40 percent of the overstory stems are minimally acceptable, consider a noncommercial weeding/cleaning to be carried out in the substandard groups. This work is expensive and should be restricted to those instances where the site is good and a marked increase in stand value will result. The operation should be the minimum required to create an overstory with at least 40 to 50 percent of the stems in acceptable species and quality.

Regeneration

Under single-tree selection, more than 90 percent of the regeneration will be tolerant species. Under group selection, based on groups averaging about one-half acre in size with all stems larger than 2 inches removed, about one-third of the regeneration will be of intermediate or intolerant species (Table 7). In larger groups up to about 2 acres in size, the intolerant and intermediate species should account for one-half of the regeneration. Limited experience indicates that the proportion of intolerants (e.g., paper birch) may equal the proportion of intermediates in groups two-thirds of an acre or larger in size.

Species composition of the regeneration under single-tree selection is closely related to the advance regeneration. Areas to be regenerated to sugar maple or softwoods should show evidence of these species in the existing advance regeneration. To be considered well established, a hardwood or hemlock stem should be 3 to 4 feet tall; a spruce or fir, about 1 foot tall.

Under group selection, the presence of residual tolerant stems in the seedling, sapling, or small-pole sizes will limit

Table 7.—Species composition of stocked milacres, 10 to 15 years after cutting in beech-birch-maple stands, by tolerance group and cutting method

Tolerance group[a]	Clearcutting	Group selection	Single-tree selection
		Percent	
Tolerant	43	62	92
Intermediate	19	34	7
Intolerant	38	4	1

[a]Tolerant: beech, sugar maple, eastern hemlock, and red spruce (also balsam-fir if present); intermediate: yellow birch, white ash, and red maple; intolerant: paper birch and aspen.

intolerant or intermediate regeneration. In regenerating birch under group selection, advanced regeneration larger than 2 inches d.b.h. should be sparse, or it should be removed in creating the opening (Fig. 3). Snow-free logging generally is more effective than winter logging in reducing unwanted advanced growth.

Group openings in poletimber stands do not always regenerate well—especially on sites that are extremely wet or dry—and are not recommended. Regeneration in groups receives more snow damage than in clearcuttings, apparently due to the extra snow that drifts into small canopy openings. But research has indicated that less than 10 percent of the groups in hardwood and mixedwood stands were in poor condition due to snow damage.

Border-tree quality is a consideration in group selection because border trees may tend to retain live limbs or produce epicormic sprouts. Poles or small sawtimber of hardwood species should not be left as border trees without trainers or buffer trees if they have (1) clear boles but small live crowns; or (2) lower live limbs that will seriously detract from quality if allowed to persist. White ash and paper birch are least likely to produce epicormic sprouts, but live limbs on any hardwood or softwood species will remain alive for a substantial period of time if exposed to full sunlight.

What constitutes adequate stocking in the seedling and sapling size classes of an uneven-aged stand? This question has not been answered completely for New England hardwood and mixedwood stands. However, in extensively

Figure 3.—Portion of a group-selection opening in nearly mature northern hardwoods. Complete removal of the understory will result in maximum amounts of intolerant-intermediate regeneration.

managed stands, the percentage of milacres stocked with at least one stem between 3 feet tall and 1.5 inches d.b.h. usually exceeds 65 percent. Percent stocking of desirable species much lower than this—below 50 percent, for example—would indicate the need for special attention to regeneration, perhaps the use of small group-selection openings. The number of stems of commercial species (1.5 to 4.5 inches, or in the 2, 3, and 4-inch classes) commonly ranges from about 200 to 450. If adequate stocking in the seedling class is present, but 2- to 4-inch saplings seem deficient, a harvest cutting to the recommended residual basal area should solve the problem. There is no concensus at present on the need for mechanical or chemical treatments to improve the composition of the seedling-sapling component under single-tree selection. Work on the Bartlett Experimental Forest with single-stem timber stand improvement in understory beech produced little permanent change at high cost. However, the subject deserves further study.

Even-Age Management

Harvesting Methods

Two even-age harvest cutting methods commonly used in the Northeast are clearcutting and shelterwood. The seed-tree method also is recommended sometimes for large cutting areas where the available seed source of desired species is limited.

Clearcutting is the harvesting of all merchantable trees on an area generally followed by a chemical or mechanical removal of trees down to 2 inches d.b.h. (Fig. 4). Sometimes groups of trees larger than 2 inches d.b.h. are left if they are of desirable species. Isolated residual trees may develop large limbs and poor quality. However, pole-size or larger sugar maple with good crowns, clear boles, and no tendency to produce epicormic sprouts will experience little

Figure 4.—Clearcutting in northern hardwoods with essentially complete removal of the understory.

degrade when left as residuals to increase the tolerant component of the new stand. Clearcutting boundaries can be designed to follow natural stand or topographic boundaries to minimize adverse esthetic impacts.

Progressive stripcutting is a variation of clearcutting that is especially well suited to the regeneration of yellow birch and other intermediate species. Strips 50 to 100 feet wide are laid out along the contour. In the first cutting, every third strip is removed; 2 to 4 years later, one strip next to each initially cut strip is removed. After another 2- to 4-year interval, the final strips are cut. Trees down to 2 inches d.b.h. are removed or felled. The material generally is skidded down the strips currently being cut, which results in a high degree of scarification and the removal of most undergrowth.

In mixedwood stands on wet areas, where windthrow would be a threat under unevenage or shelterwood systems, narrow strips (30 to 50 feet wide) sometimes are used to help perpetuate a softwood component. Winter logging usually is advisable in these areas, and softwood regeneration is most probable if the strips contain established softwood seedlings.

In the Northeast, the shelterwood system commonly is applied in two cuts: an initial seed cut (Fig. 5) and a final removal cut. Where the objective is to regenerate tolerant species and little or no advanced regeneration is present, an initial light preparatory cut also may be desirable to stimulate seed production of desirable species and the establishment of small seedlings. For tolerant regeneration, the seed cut should retain about 80 percent crown cover

Figure 5.—Shelterwood seed cut in northern hardwoods leaving approximately 70 percent crown cover (approximately 60 ft^2 of basal area per acre). Marking from below followed by brush saw removal of stems under 5.0 inches d.b.h. has created ideal conditions for regenerating tolerant and moderately tolerant species.

for hardwoods (60 to 70 ft^2) and softwoods (100 to 120 ft^2); for intermediately tolerant regeneration (chiefly yellow birch), the seed cut should leave a residual stand of about 30 to 50 percent crown cover (30 to 40 ft^2); perhaps a little higher on wet sites. Marking for seed cuts (and preparatory cuts) must be from below, removing smaller stems as first priority, and leaving a uniformly distributed stand. Tables 17–19 in the Appendix help relate crown cover to basal area by species group. These tables allow shelterwood prescriptions to be written in terms of crown cover or basal area, or both.

The final removal cut for any species should be made when the regeneration is 3 to 4 feet tall or more for most species (> 2 feet for birch; > 1 foot for spruce). Winter removal minimizes logging damage to the regeneration. However, summer removal is a possibility with hardwoods because of their sprouting ability. Other logging precautions to minimize damage to the regeneration include the careful layout of major skid trails, directional felling, log-length skidding, and the use of winching devices.

In previously cutover stands, where a good stocking of saplings and poles are present under an existing overstory, a natural shelterwood can be applied simply by removing the overstory. The main concerns are damage to, and adequate stocking in, the residual stand. Several planned modifications to the shelterwood system have been tried where the time between the seed cut and removal cut has been lengthened to maintain continual cover for esthetic purposes; these are known as delayed or extended shelterwoods. In the extreme, this approach becomes a two-age system where removal cuts are made at half-rotation intervals.

Dense, undesirable understory vegetation will hinder the establishment of regeneration under the shelterwood system. Methods for dealing with this problem include understory biomass operations, broadcast chemical treatments, and the mechanical or chemical treatment of individual unwanted stems.

The shelterwood system is a good option in mixedwood stands, especially those with high sawtimber potential. This system can be used to increase the tolerant softwood component; to maintain windfirmness if high residual crown cover is maintained; and to allow for the use of large equipment that tends to destroy understory saplings and poles.

Regeneration

Species favored by clearcutting and dense or open shelterwood cutting are summarized in Table 2. Clearcuttings commonly have 20,000 to 30,000 or more stems per acre 1 foot tall or taller at 5 years of age. Species composition is more important than numbers. About two-thirds of the milacres on clearcut areas generally are dominated with intolerant or intermediately tolerant species, though the proportion based on total numbers is less. If advanced regeneration of tolerants larger than 2 inches d.b.h. is retained, a somewhat lower proportion of intolerants-intermediates will result. Tolerant softwoods seldom regenerate well following clearcutting unless well-established regeneration is present—a type of natural or unplanned shelterwood.

One approach to evaluating regeneration following clearcutting is to take a series of circular plots, each 1/700 to 1/1,000 acre in size (8.9 to 7.4 feet in diameter). These plot sizes represent the area occupied by each tree when the stand reaches 4 to 6 inches d.b.h. (quadratic mean stand diameter or tree of average basal area) in the northern hardwood and mixedwood stocking guides (Figs. 6–7). Determine and record the dominant free-to-grow species—the species that will dominate the plot using all available information on tolerance, relative growth rate, longevity, etc. If the proportion of plots dominated by desirable species exceeds 60 percent (many plots contain more than one commercial stem), this would be equivalent to B-line stocking or better. Stocking of 40 percent would be about equivalent to C-line stocking. By also recording the desired species present that are not free to grow, it is possible to determine whether the species potential of each plot could be improved by a weeding operation. For example, a plot might be dominated by free-to-grow aspen; if removed, the plot might be dominated by paper birch. In summarizing the data, it is then possible to examine stocking of acceptable species both with and without treatment. If the without-treatment stocking is less than C line, but the with-treatment stocking is well above the C line, a weeding/cleaning operation should be considered.

Data from shelterwood cuttings in the Lake States indicate that at least 5,000 well-distributed seedlings per acre, 3 to 4 feet tall, should be present before the removal cut. After the removal cut, the regeneration can be evaluated using the plot system described for clearcutting.

In the past, scarification has been recommended for yellow and paper birches since most studies show much higher stocking of these birches on scarified seedbeds. However, scarification operations are expensive and difficult to justify. Recent experience indicates that summer logging, which encourages a small amount of scarification from the logging operation, does not necessarily produce more birch than winter logging.

Scarification during the seed cut of a shelterwood has been recommended in the Lake States for regenerating hemlock. In the Northeast, certain sites—notably the wetter ones—appear to develop a strong understory of hemlock without scarification. However, on drier mixedwood sites where little or no advance regeneration of hemlock is present, scarification during the shelterwood seed cut would appear to be helpful.

Planting is seldom done on a commercial scale in northern hardwoods and related types in the Northeast. However, where seed sources of desired species are lacking or genetically improved trees are desired, planting can be done successfully. We recommend container-grown stock for rapid growth and minimum mortality. The planting site needs to be freed of brush or sod—by mechanical or chemical means—to at least 3 to 4 feet around each seedling location. Posttreatment release often is necessary. In some areas, it also will be necessary to control damage from deer, rabbits, and mice. Yellow and paper birches, spruce, and hemlock all are possible planting candidates.

Stocking

Stocking guides for even-aged hardwood stands are given in Figure 6 and for mixedwood stands in Figure 7. The guides apply to the main crown canopy, i.e., excluding the suppressed trees. Mixedwood stocking applies to stands with 25 to 65 percent softwoods in the main crown canopy. The A lines represent the average density of undisturbed even-aged stands. The B lines represent the minimum density for maximum basal area or cubic-foot growth. The charts were developed from both simulated and remeasured plot data which show that maximum growth per acre occurs at about 55 to 65 ft^2 of basal area in hardwoods. The C line represents minimum stocking—the minimum amount of acceptable growing stock to make the stand worth managing. The C line is roughly 10 years' growth below the B line. Growth per acre (in basal area or cubic feet) is a little lower at the C line than the B line, and diameter growth more rapid.

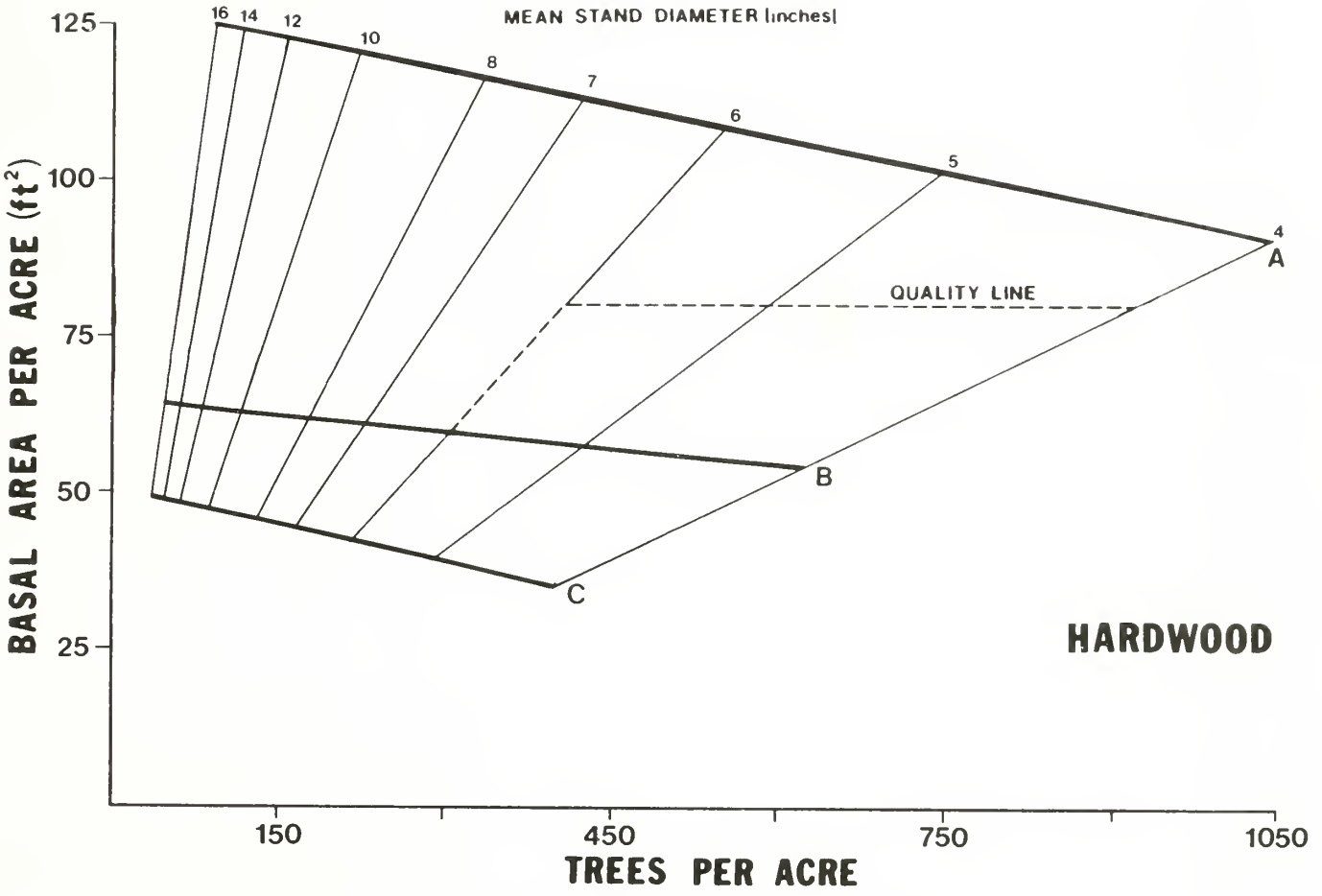

Figure 6.—Stocking guide for main crown canopy of even-aged hardwood stands (beech-red maple, beech-birch-maple) shows basal area and number of trees per acre and quadratic mean stand diameter. The A line is fully stocked, the B line is suggested residual stocking. The C-line is minimum stocking. The quality line is the density required to produce high quality stems of beech, sugar maple, yellow birch, and red maple.

Average density of mixedwood stands is higher than that of hardwood stands (Figs. 6–7). The mixedwood A line is from 20 to 55 ft^2 above the hardwood A line. Similarly, the B line is from 35 to 45 ft^2 above the hardwood B line when the percentage of softwood is from 25 to 65 percent of the basal area of trees in the main crown canopy.

A Quality line also is shown for hardwoods (Fig. 6). Limited research indicates that species such as beech, sugar maple, red maple, and yellow birch do not prune well naturally unless grown at 80 ft^2 of basal area per acre. Paper birch, aspen, and white ash appear to be the only common hardwoods in the Northeast that will develop acceptable quality in small poletimber stands maintained at or near the B line. At average stand diameters of about 6 inches, clear lengths of about 1 1/2 logs should be present on many trees. At this time or after additional clear bole development the stand can be thinned back to the B line (plus 5 to 10 ft^2 to allow for logging damage), perhaps in two operations if basal area is high and crowns are small. Up to stand diameters of roughly 6 inches, light improvement work to maintain species composition and select for stem quality is acceptable. The Quality line in Figure 6 is dotted because species compostion and local experience will influence the level of stocking required in young stands to ensure quality development. To grow limb-free or small limbed hemlock and spruce, density should be maintained

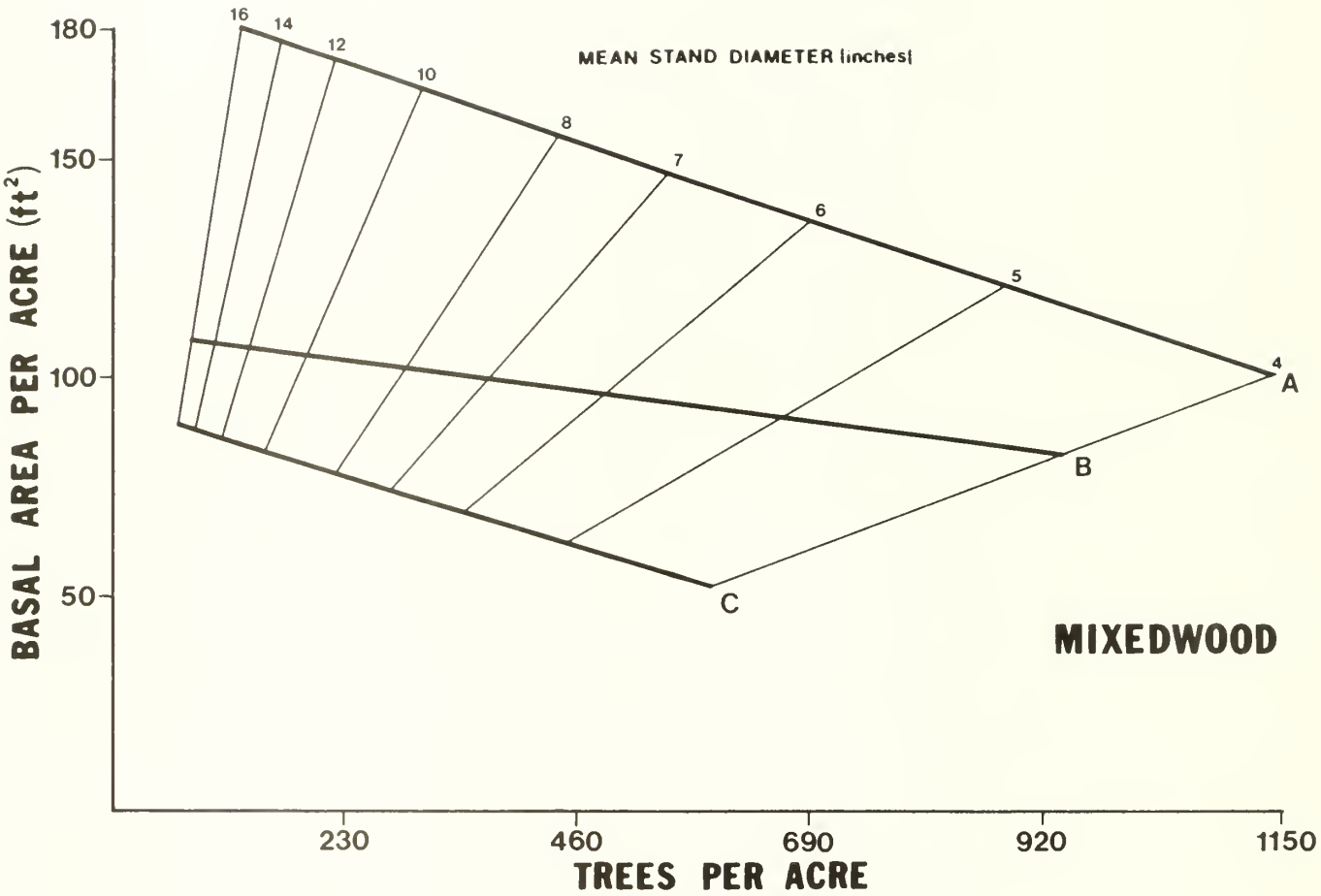

Figure 7.—Stocking guide for main crown canopy of mixedwood stands (25 to 65 percent softwoods) shows basal area and number of trees per acre and quadratic mean stand diameter. The A line is fully stocked, the B line is suggested residual stocking, the C line is minimum stocking.

near the mixedwood A line for stands with a mean stand diameter less than 6 inches.

Growth, Yield, and Rotation

Board-foot and cubic-foot volumes per acre for unmanaged hardwood stands are given in Table 8, based on simulation (Solomon and Leak 1985). These are gross yields with no deduction for cull or defect. Cubic volumes of mixedwood are at least 15 to 25 percent greater than hardwood yields, and board-foot volumes may be proportionately even greater. However, precise estimates of mixedwood yields are not yet available. Yields of intensively managed hardwood stands are simulated in Table 9. These yields are for stands kept at 80 ft^2 or more of basal area until the mean stand d.b.h. reached 6 inches, and then thinned to B-line density when stand basal area was about two-thirds the distance from B line to A line. Hardwood yields represent the maximum attainable under intensive silviculture in a natural stand and total managed yields at about 100 years of age are 50 to 90 percent greater than unmanaged yields. In applying both the managed and unmanaged yield tables, deductions from gross yields must be made for sound and rotten cull, logging waste, poor stocking, and nonforest acreage.

The site indexes in Tables 8 and 9 are for sugar maple, base age 50. Sugar maple sites of 70 and above commonly occur in New England on soils enriched by organic matter or derived from rich bedrock (e.g., limestone) or alluvium. Sugar maple and ash are common on such sites. Sites of 60 to 70 typically are beech-birch-maple sites; the soils are well- to moderately well-drained, fine-textured tills. Sites of

Table 8.—Volumes per acre in cubic feet (4.0-inch ib top) and board feet (8.0-inch ib top) for unmanaged hardwood stands, by site index, mean stand diameter, and age

Mean d.b.h. (inches)	Site 50			Site 60			Site 70		
	Age	Cubic feet	Board feet	Age	Cubic feet	Board feet	Age	Cubic feet	Board feet
	Years			*Years*			*Years*		
4.0	35			30			25		
6.0	59	1289		49	1547		41	1821	
8.0	83	1606	2983	67	1924	3560	55	2254	4258
10.0	120	1934	5554	87	2311	6640	69	2675	7632
12.0	182	2272	8259	114	2700	9783	85	3144	11461
14.0				157	3102	13048	102	3579	15079
16.0				196	3154	13257	127	3654	15390

50 to 60 tend to be beech-red maple or mixedwood sites; soil productivity is limited somewhat by shallow, compacted layers, coarse textures, restricted aeration, or excessive stoniness. Sites below 50 usually are poorly drained or shallow to bedrock. Sites below about 50 to 55 are best suited to growing softwoods, or hardwoods on shorter rotations (e.g., paper birch and aspen).

Rotation age usually is based on (1) the culmination of mean annual increment, or (2) the time required to grow a certain-size tree or product. Tables 8 and 9 indicate that culmination of mean annual board-foot growth in both managed and unmanaged stands ranges from about 100 to 120 years. Mean diameters at the point of culmination vary with site—the range is 14 to 18 inches. Culmination of mean annual increment for cubic volume occurs at age 40 to 50 in unmanaged stands and 80 to 90 years in managed stands. In Table 9, some inconsistency is evident in the trend of mean annual increment because of the timing of intermediate cuts.

Intermediate Cuttings

Where there are good markets for pole-size material, noncommercial thinning/cleaning often is not needed; in many cases, silvicultural needs can be met through commercial operations in pole stands. However, if an analysis of the reproduction following clearcutting or shelterwood cutting indicates that desired species objectives will not be met (see section on even-age regeneration), a noncommercial operation may be warranted. The silvicultural objective should be to increase the proportion of plots dominated by acceptable species to about 40 percent (equivalent to C-line stocking). Where the objective is to increase the proportion of softwood species, cleaning can be done in seedling stands with selective herbicides. To change the species mix in hardwood stands, mechanical or chemical stem treatments should be done in stands between about 10 to 20 years of age. Examples where noncommercial work might be warranted are in: (1) mixedwood regeneration where the objective is to grow softwoods; (2) mixtures of valuable hardwoods (yellow birch, sugar maple, ash) in combination with fast-growing less valuable species such as red maple; (3) other situations where economic analysis indicated that costs are justified.

In most hardwood stands between 4 and about 6 inches mean d.b.h., the stocking guide (Fig. 6) recommends fairly high stocking for those species that are resistant to natural pruning. Improvement work during this period might be accomplished by light, commercially marginal operations that remove 15 to 25 ft^2 of basal area per acre. In stands of paper birch, ash, and aspen averaging 4 to 6 inches d.b.h., heavier cuttings down to the B line are permitted for fuelwood or pulp.

Pruning is not a common silvicultural treatment in northern hardwoods. But the high value differential between clear and knotty logs is reason enough to continue to exam the prospective costs and returns from this practice. Pruning probably is most feasible for valuable species that are moderate to poor self-pruners: sugar maple, yellow birch, and red oak. Prune trees that are about 4 to 6 inches during the late summer or dormant season; do not remove more than a third of the live crown. Do not flush cut. Place the saw just outside the branch bark ridge and cut downward and slightly outward.

Table 9. Volumes per acre in cubic feet (4.0-inch top) and board feet (8.0-inch top) for intensively managed even-aged hardwoods

Mean d.b.h. (inches)	Site 50							Site 60							Site 70						
		Cumulative thinnings		Standing		Total			Cumulative thinnings		Standing		Total			Cumulative thinnings		Standing		Total	
	Age	Cubic feet	Board feet	Cubic feet	Board feet	Cubic feet	Board feet	Age	Cubic feet	Board feet	Cubic feet	Board feet	Cubic feet	Board feet	Age	Cubic feet	Board feet	Cubic feet	Board feet	Cubic feet	Board feet
	Years							*Years*							*Years*						
4.0	35							30							25						
6.0	57	226		1158		1384		48	269		1418		1687		40	315		1657		1972	
8.0	74	1012	726	996		2008	2698	61	1243	895	1189	2211	2432	3106	50	1439	1075	1426	2760	2865	3835
10.0	89	1012	726	1608	4694	2620	5420	72	1243	895	1912	5471	3155	6366	59	1439	1075	2222	6400	3661	7475
12.0	105	1520	2211	1725	6409	3245	8620	83	1854	2680	2039	7375	3893	10005	68	2148	3171	2395	8807	4543	11978
14.0	124	2128	4596	1738	7502	3866	12098	95	2602	5633	2011	8449	4613	14082	77	3019	6650	2389	10139	5408	16789
16.0	147	2786	7435	1469	6340	4255	13775	107	2602	5633	2449	10289	5051	15922	85	3019	6650	2868	12203	5887	18853
18.0								119	3394	8960	2085	8760	5479	17720	92	3915	10465	2446	10446	6361	20911

Beyond 6 inches mean diameter, commercial thinnings generally will be feasible, lowering the basal area to about the B-line level (perhaps in two operations) plus an allowance of 5 to 10 ft^2 for logging damage. Then, when a stand reaches one-half to three-fourths of the distance from the B line to the A line, additional commercial thinnings can be made to reduce the basal area back to B-line level (plus damage allowance). Most commercial thinning will be in the main crown canopy, removing dominant, codominant, and intermediate trees. Keep in mind that certain types of marking (from above, from below) may change the residual mean diameter and also the appropriate B line. The objective is to provide adequate growing space for the stems with highest value potential by removing:

1. Risk trees: Valuable trees that will not last until the next thinning, or that will experience severe degrade.

2. Unacceptable stems: Trees that will not produce sawlog material now or in the future due to defect or cull.

3. Undesirable species.

4. Acceptable stems crowding high-value stems.

Stand Evaluation

Reproduction and Sapling Stands

In these young even-aged stands (mean stand diameter up to 4.0 inches) the primary need is for a method of judging the adequacy of stocking and species, and predicting the need for early noncommercial treatment.

To determine stocking, sample about 2 plots per acre in each young stand up to a total of about 50; plot size should be 8.9 feet (1/700 acre) or 7.4 feet (1/1,000 acre) in diameter. Record:

1. The species that will dominate the plot if left untreated. This requires the application of all available knowledge on species growth rates, tolerance, longevity, etc.

2. The desirable species not free to grow (commercial or desirable species) that will dominate the plot if one or two undesirable overstory stems are removed.

If at least 40 to 60 percent of the plots are dominated by desirable free-to-grow stems, the stand should attain C-line or B-line stocking of acceptable species when it reaches the lower end of the stocking guide. If stocking of desirable free-to-grow stems is less than 40 percent, the stocking of desirable species not free to grow should be examined to determine whether a precommercial operation will raise the representation of desirable species to C-line or B-line levels.

Poletimber and Sawtimber Stands

These are even-aged or uneven-aged stands with mean diameters larger than 4.0 for trees in the main crown canopy. Take a minimum of 10 systematically located sample points in uniform stands, and up to 30 points in variable stands. On a cumulative tally (Table 10) (or a conventional tally and with the data in Table 11) record trees counted with a 10-factor prism by 2-inch diameter classes, and the following tree classes (denoted by the tally legend):

1. Species or species group (optional)

2. Acceptable growing stock

   a. Mature trees (optional if species are tallied)

   b. Immature trees (optional)

3. Unacceptable stems

   a. Defective (optional)

   b. High risk (optional)

   c. Cull (optional)

For uneven-age management, the tally should include all trees in the 6-inch class and larger. For even-age management, the tally should include all trees in or touching the main crown canopy (exclude the suppressed trees). Where the choice has not yet been made between even-age and uneven-age management, the tally legend should distinguish between suppressed trees and those in the main crown canopy. Acceptable growing stock will produce sawlog or better material now or in the future. Unacceptable stems will not. Maturity can be tallied in the field using the size guidelines in Table 5, and current tree condition can be noted. If the tally legend separates species or species groups, maturity can be scored later using the general guidelines at the bottom of Table 12. Also, in even-age stands, measure breast height age and total height for up to five dominant stems per stand to determine site index (Figs. 8–9). Determine whether the stand is beech-birch-maple, beech-red maple, or mixedwood. And judge on the ground whether a commercial cutting is now feasible; this judgment should be based on volume, quality, accessibility, and markets.

Table 10. Sample cumulative tally for a 10- or 20-factor prism (example for two plots)

BA Factor		Diameter at breast height (inches)												
10	20	2	4	6	8	10	12	14	16	18	20	22	24	26
No. trees		*No. trees per acre*												
1		458	115	51[X/]	29[/]	18[/]	13[0]	9[0]	7[/]	6[M]	5	4	3	3
2	1	917	229	102[X/]	57[0]	37[/]	25[/]	19[0]	14[0]	11[0]	9	8	6	5
3		1375	344	153	86[/]	55[/]	38[0]	28[/]	21[0]	17	14	11	10	8
4	2	1834	458	204	115	73[/]	51[0]	37[0]	29	23	18	15	13	11
5		2292	573	255	143	92[0]	64	47	36	28	23	19	16	14
6	3	2750	688	306	172	110	76	56	43	34	27	23	19	16
7		3209	802	357	201	128	89	65	50	40	32	27	22	19
8	4	3667	917	407	229	147	102	75	57	45	37	30	25	22
9		4125	1031	458	258	165	115	84	64	51	41	34	29	24
10	5	4584	1146	509	287	183	127	94	72	57	Tally		No.	
11		5042	1260	560	315	202	140	103	79	62	Legend		Plots	
12	6	5501	1375	611	344	220	153	112	86	68	/Acceptable		. .	
13		5959	1490	662	372	238	165	122	93	74	0 Unacceptable			
14	7	6417	1604	713	401	257	178	131	100	79	X Suppressed			
15		6875	1719	764	430	275	191	140	107	85	M Mature			
Trees/acre:				51	43	46	25.5	18.5	10.5	5.5	Total = 149			
BA/acre:				10	15	25	20	20	15	10	Total = 105			

Trees/acre: Add the last numbers used in each column and divide by the number of plots.

BA/acre: Add the number of entries; multiply by the BA factor; and divide by the number of plots.

BA factor 10: Use the numbers consecutively in each column. For example, one 10-inch tree in a plot represents 18 trees per acre; two 10-inch trees represents 37 trees.

BA factor 20: Use the second number of each pair in a column. For example, one 10-inch tree in a plot represents 37 trees per acre; two 10-inch trees represents 73 trees.

Site-Index Trees:	*Species*	*Age*	*Height*	*Type:* Beech-birch-maple
	SM	70	70	

Table 11.—Basal area per tree and numbers of trees per acre conversion for a 10-factor prism

D.b.h.	Prism conversion	Basal area per tree	D.b.h.	Prism conversion	Basal area per tree	D.b.h.	Prism conversion	Basal area per tree
Inches	*No. trees/acre*	*Ft²*	*Inches*	*No. trees/acre*	*Ft²*	*Inches*	*No. trees/acre*	*Ft²*
1.0		0.0055	11.5		0.7213	22.0	3.8	2.6398
1.5		.0123	12.0	12.7	.7854	22.5		2.7612
2.0	458.4	.0218	12.5		.8522	23.0	3.5	2.8852
2.5		.0341	13.0	10.8	.9218	23.5		3.0121
3.0	203.7	.0491	13.5		.9940	24.0	3.2	3.1416
3.5		.0668	14.0	9.4	1.0690			
4.0	114.6	.0873	14.5		1.1467			
4.5		.1104	15.0	8.2	1.2272			
5.0	73.3	.1364	15.5		1.3104			
5.5		.1650	16.0	7.2	1.3693			
6.0	50.9	.1963	16.5		1.4849			
6.5		.2304	17.0	6.3	1.5763			
7.0	37.4	.2673	17.5		1.6703			
7.5		.3068	18.0	5.7	1.7671			
8.0	28.6	.3491	18.5		1.8667			
8.5		.3941	19.0	5.1	1.9689			
9.0	22.6	.4418	19.5		2.0739			
9.5		.4922	20.0	4.6	2.1817			
10.0	18.3	.5454	20.5		2.2921			
10.5		.6013	21.0	4.2	2.4053			
11.0	15.2	.6600	21.5		2.5212			

The essential information from the plots can be summarized (Table 12) to provide a basis for either the uneven-age or even-age stand options. For the uneven-age summary, the first six basal area columns provide a description of the initial stand; not all columns need be used, or more can be added to provide a species breakdown. From these data, the initial percentage of sawtimber can be determined, as can the initial approximate q from the tabulation in the section on uneven-age stocking. If the prescription key suggests a harvest cutting, the residual goal is determined by: (1) examining various approaches (marking rules) for removing the poorer quality material so as to leave a good-quality stand with the required total basal area; *or* (2) using a residual goal based on the initial q of the stand; *or* (3) using the general guidelines in Table 6. The marking goal is simply the difference between the initial total basal area and the residual goal; however, 5 to 10 ft^2 may be subtracted from the marking goal for logging damage.

For the even-age summary, basal area of the initial stand is listed by tree condition class. Number of trees per acre is taken from the cumulative tally. Total basal area per acre and number of trees are used to read mean stand diameter from the stocking chart (Figs. 6–7). Basal area at the A, B, C, and Quality lines also are taken from the stocking chart. If the prescription key calls for a treatment, the residual goal generally is determined by the B line or Quality line. However, residual goals higher than the B line may be prescribed to maintain maximum amounts of quality material, for esthetic purposes, etc. The marking goal is the difference between the initial and residual, minus any allowance for logging damage. Distributing the residual goal and marking goal among tree condition classes helps in the development of marking guides and helps ensure that the treatment will improve the quality of the stand.

Stand Prescription

Key

Use the following key to identify the stand condition and find the appropriate prescription (A, B, C, etc.). Details of the prescriptions follow the key. Also, consult the appropriate section describing the treatment within the text.

Table 12.—Summary table for uneven-aged or even-aged stand diagnosis (example from Table 10)

D.b.h. class (inches)	Mature	Immature	Defective	High risk	Cull	Total	Possible residual goals (Q = 1.5-1.7)		Possible marking goals	
					Ft					
					UNEVEN-AGED					
6–10		40	10			50	30	38	20	12
12–14		10	30			40	20	18	20	22
16+	5	5	15			25	20	14	5	11
All	5	55	55			115	70	70	45	45

Initial % Sawtimber = 57 Initial Q = 1.5

EVEN-AGED

Tree condition	Initial stand	Residual goal	Marking goal
		Ft²	
Mature	5	5	0
Immature	45	45	0
Defective-high risk	55	14	41
All	105	64	41

No. Trees 149
MSD 11.4
A line BA 112
B line BA 64
C line BA 48
Quality line BA ___
Bole Condition:
___ Clear merchantable length
___ More natural pruning needed

Commercial Cutting
___ Feasible
___ Not feasible

Mature D.b.h. (inches)
20 – SM, YB, WP, Hem
18 – Be, WA, RO
16 – RS, RM
12 – PB, Asp., BF

Site-Index Trees

	B		
Species		___	___
Age	70	___	___
Height	70	___	___
Site	60	___	___

Reproduction or Sapling Stands (Mean d.b.h. of Overstory Less Than 4.0 Inches)

1. 40 percent or more of the plots stocked with a desirable free to grow stem (untreated). A

1. Less than 40 percent of the plots stocked with a desirable free to grow stem (untreated).

2. More than 40 percent, preferably more than 60 percent, of the plots stocked with a desirable stem not free to grow. B

2. Less than 40 percent of the plots stocked with a desirable stem not free to grow. C

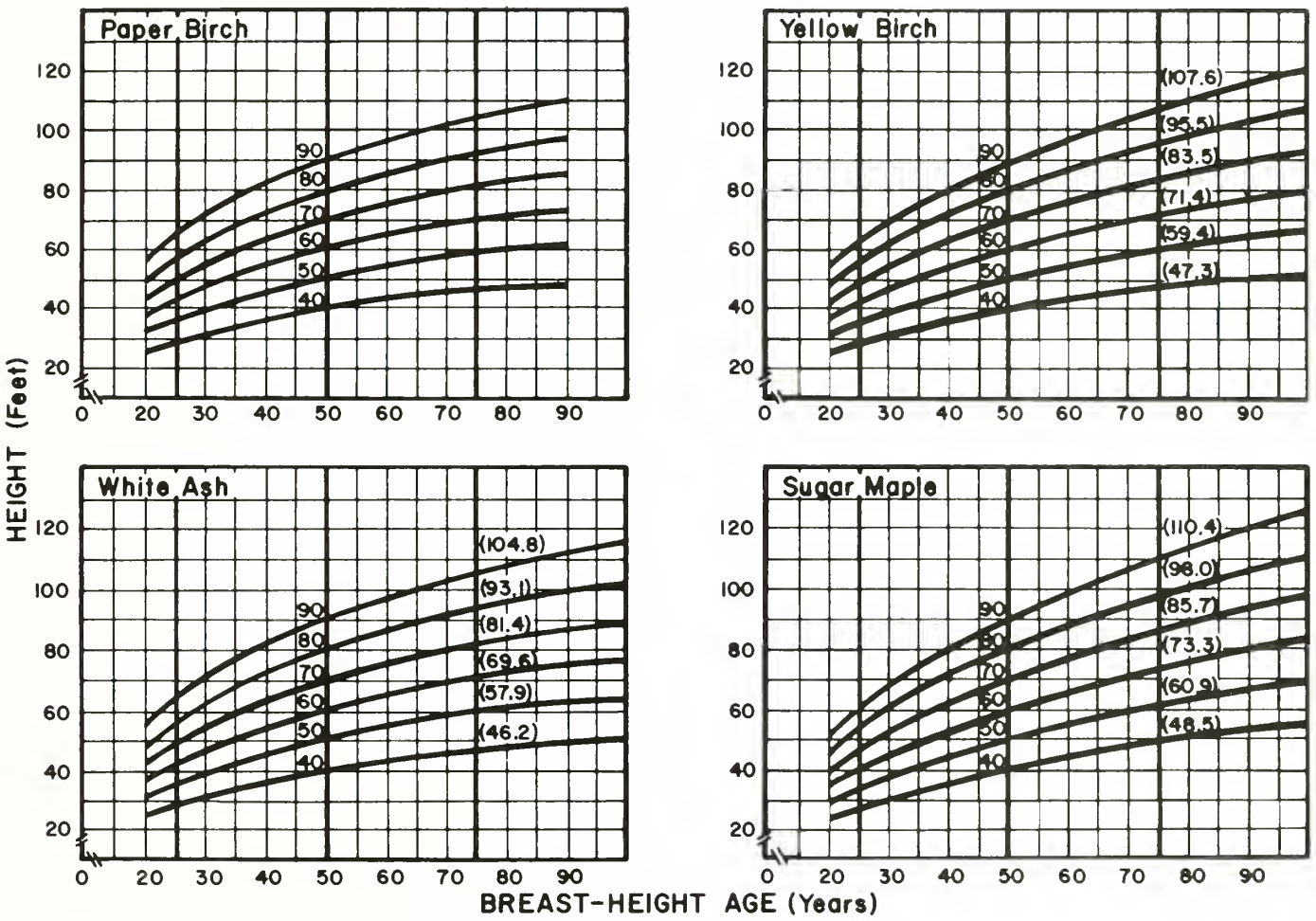

Figure 8.—Site-index curves (breast height age 50) for paper birch, white ash, yellow birch, and sugar maple in Vermont and New Hampshire. Values in parentheses are for site-index breast height age 75 (Curtis and Post 1962b).

Poletimber and Sawtimber Stands (mean d.b.h of overstory 4.0 inches or more)

1. Objective: uneven-age management
   2. Acceptable mature and immature growing stock more than:
      40 ft^2 (hardwood stand) or
      60 ft^2 (mixed-wood stand)
      3. Acceptable mature and immature growing stock 12 inches and larger more than:
         25 ft^2 (hardwood) or
         40 ft^2 (mixedwood)
         4. Total basal area more than:
            100 ft^2 (hardwood) or
            130 ft^2 (mixedwood) D
         4. Total basal area less than:
            100 or 130 ft^2 E
      3. Acceptable mature and immature growing stock 12 inches d.b.h and larger less than:
         25 ft^2 (hardwoods) or
         40 ft^2 (mixedwood)
         4. Total basal area more than:
            100 ft^2 (hardwood) or
            130 ft^2 (mixedwood) F
         4. Total basal area less than:
            100 or 130 ft^2 G
   2. Acceptable mature and immature growing stock less than:
      40 ft^2 (hardwood) or H
      60 ft^2 (mixedwood)
1. Objective: even-age management
   2. Stocking of acceptable growing stock less than C line for the appropriate type I

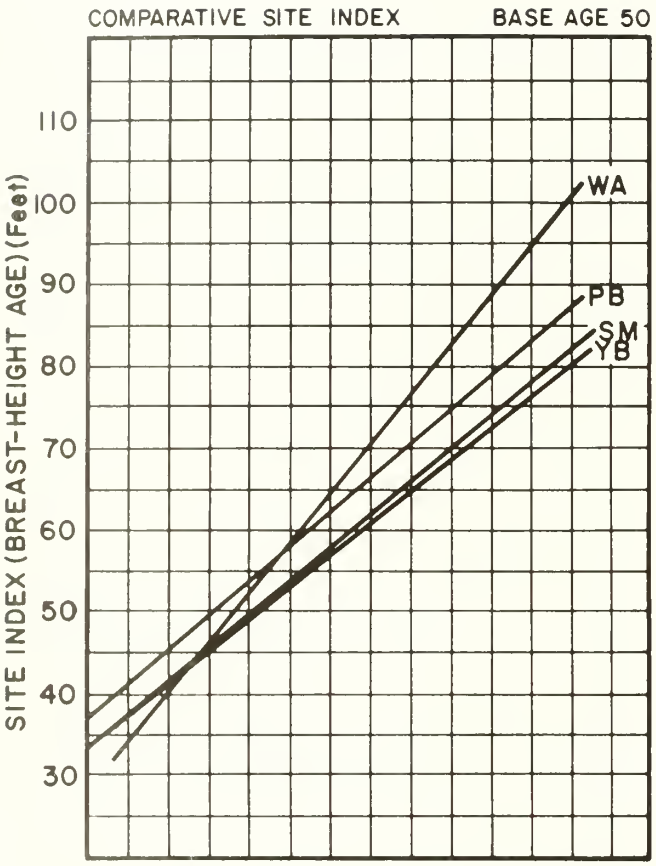

Figure 9.—Relationships among site indices (base age 50) for white ash, paper birch, yellow birch, and sugar maple. To estimate site index of species X from site index of species Y: find known site index on curve for species Y; move vertically up or down to curve until species X is located; read horizontally across to the left to find estimated site index for species X (Curtis and Post 1962a).

2. Stocking of acceptable growing stock more than C line
   3. Stand mature[1/]
      4. Objective: intolerant and intermediate species — J
      4. Objective: tolerant species — K
   3. Stand not mature
      4. Stand more than 6 inches mean stand diameter and adequate clear length developed
         5. Total stocking more than halfway between A and B lines
            6. Commercial thinning feasible now or within 10 years — L
            6. Commercial thinning not feasible now or within 10 years — M
         5. Total stocking less than halfway between A and B lines — N
      4. Stand less than 6 inches mean stand diameter, or clear length not well developed
         5. Total stocking more than Quality line
            6. Light commercial thinning feasible now or within 10 years — O
            6. Light commercial thinning not feasible now or within 10 years — P
         5. Total stocking less than Quality line — Q

[1]Mature: (1) at rotation age, (2) at mature size, based on product objectives, or (3) 50 percent or more of the basal area in mature trees.

Prescriptions

A. This young stand should develop naturally into an adequate pole stand with at least C-line stocking of desirable species. Noncommercial treatment is not required.

B. This young stand will develop into a pole stand with C line stocking of desirable species only if cleaned precommercially. Benefits and costs of such treatment should be examined using all available information on site, species response, and managment objectives. Apply the treatment if warranted.

C. Even if cleaned precommercially, this young stand will not develop C-line stocking of desirable species. Reexamine the stand in 10 to 20 years to determine the best treatment options—including the possibility of biomass harvesting for fuel or fiber.

D. This stand has suitable quality, structure, and basal area to implement uneven-age management. Develop and apply marking guides to meet goals for residual basal-area structure, tree condition, and regeneration. Consider both single-tree and group selection.

E. This stand has suitable quality and structure to implement uneven-age management. But stand density is not critically high. Reexamine in 10 to 20 years, unless the possible loss of valuable high-risk trees warrants immediate harvest cut by selection or group-selection methods.

F. This stand has suitable quality and density to initiate uneven-age management, but sawtimber stocking is low. Apply a commercial improvement cut, removing lower quality overstory stems, leaving a residual basal area of about 65 to 70 ft^2 (hardwood) or 80 to 100 ft^2 (mixed wood) per acre plus any allowance for logging damage.

G. This stand has suitable quality for uneven-age management, but sawtimber stocking is low and stand density is not critically high. Reexamaine in 10 to 20 years.

H. This stand has too little quality growing stock for efficient uneven-age management. Reconsider the possibility of even-age management through clearcutting or shelterwood cutting. The other alternative is a long series of improvement cuts and selection/group selection to gradually improve the condition of the stand.

I. Acceptable growing stock is inadequate. Plan to regenerate the stand with clearcutting, strip cutting, or shelterwood cutting when commercially feasible.

J. Apply clearcutting to maximize the proportion of intolerant and intermediate species. Strip cutting should maximize intermediates such as yellow birch. In sensitive areas, a heavy two-cut shelterwood can be applied by leaving 30 to 50 percent residual crown cover (30 to 40 ft^2) following the seed cutting and removing the overstory in about 5 years.

K. Use a light two-cut shelterwood, leaving about 80 percent or more crown cover (60 to 70 ft^2 of basal area), during the initial seed cutting and removing the overstory when the tolerant advanced regeneration is more than 3 feet tall.

L. This immature stand has adequate young growing stock for even-age management, and sufficient stand density to support a commercial thinning. Stands should be thinned to not below the B line. However, only up to one third of the main canopy basal area should be removed at any one time. In stands within about 20 years of maturity, commercially thin only if there will be losses in volume or value if the stand is left untreated until final harvest.

M. This immature stand has adequate acceptable growing stock and density for even-age management, but commercial thinning is judged not feasible because of accessibility, current markets, etc. Leave untreated until commercial thinning prospects improve.

N. This immature stand has adequate acceptable growing stock for even-age management, but stand density is not critically high. Reexamine in 10 to 20 years.

O. This immature stand has sufficient potential quality and density for even-age management, but adequate clear length has not yet developed. Light thinning or improvement cutting to the Quality line, removing a small amount of poor quality or risky material, is permitted; this option is best suited to stands where quality, species, and site index are above average.

P. This immature stand has sufficient quality and density for even-age management, but adequate clear length has not yet developed. Light thinning is judged not feasible. Leave untreated, and reexamine in 10 years.

Q. This immature stand has sufficient potential quality for even-age management, but adequate clear merchantable length has not yet developed. For production of quality material, leave the stand untreated so that increasing stand density will encourage natural pruning. For fuelwood production, the stand may be thinned to B line.

Regulation

Regulation refers to the methods used to control the amount and periodicity of timber yields from a property. Commercial timberland owners, industrial owners, and certain large public ownerships may need regular, sustained or increasing yields. Owners of small tracts may have less need to control yields.

With uneven-age management, periodic yields from each stand or group of stands are achieved by setting a residual stand density, structure, and growing-stock condition (in terms of risk and quality potential) that will produce good volume or value growth over the cutting cycle (see Tables 3 and 4).

The first cut in a heavily stocked stand will produce fairly high gross yields, but may be low in net yield and value. Ensuring harvests in any stand are made at intervals equal in length to the cutting cycle. During these harvests, residual stand density is roughly consistent, though the proportion and quality of the residual sawtimber may be increased gradually until it reaches a desirable level. This approach will result (after the first cut) in fairly constant cubic-foot yields roughly equal to annual growth times the cutting cycle, and gradually increasing sawtimber yields until an essentially constant level is reached.

On a large uneven-aged property, where annual yields are feasible and desired, the entire property can be divided into a number of cutting units or groups of stands equal to the years in the cutting cycle. Then, each year, a different cutting unit is harvested to provide an annual yield. At the outset, units are entered in order of priority based on maturity, risk, stocking, etc.

Uneven-age regulation commonly is called volume, basal area, or growing-stock control. However, since the cutting units will have roughly equal acreages (or acreages inversely proportional to productivity), there is some element of area control involved as well.

The system becomes more complicated when there are inaccessible or less productive areas on a long cutting cycle, and productive or accessible areas on a short cutting cycle. Detailed scheduling is required to assure that roughly equal yields are harvested each year. A more formal approach is to divide the inaccessible lands into a number of cutting units equal to the number of years in the long cutting cycle, and also to divide the accessible lands into a number of cutting units equal to the years in the short cutting cycle. Then, each year, both an inaccessible and an accessible unit are cut. This approach tends to regulate both yields *and* access costs.

With even-age management, there are two components to the yield: harvest-cutting and thinning yields. In theory, an even-aged forest is fully regulated when it has roughly equal acreages in each 10- or 20-year stand age class from the youngest class up to the class representing the planned rotation age. As with uneven-age management, it sometimes is practical to: (1) divide the entire property into type or accessibility classes, (2) set an appropriate rotation age and thinning interval for each class, and (3) work toward an balanced age distribution in each type of accessibility class. To develop a balanced age distribution, harvest an acreage per year equal to the total acreage divided by the planned rotation age. If the entry period for harvest cutting is more than 1 year, multiply by the number of years in the entry cycle to determine the acreage to harvest at each entry.

Thinned acreage commonly is 2 or 3 times the harvest acreage, though thinned volume may be between 50 and 100 percent of the harvest yields. In an unbalanced even-aged forest, the thinning yields will be variable because: (1) the acreage in each age class will be unequal, and (2) the quality and stocking of some acres in each age class may not warrant thinning.

Economic Considerations

With moderately intensive silviculture, managed stands can yield at least 50 percent more volume than unmanaged stands. Although the increased physical yields seem worth pursuing, the financial returns from those yields may not be. The following discussion explores the economic effectiveness of applying silvicultural guidelines in the management of northern hardwood forests.

We develop a generalized case to trace the changes in timber values that we might expect in northern hardwood stands over long periods of time under various management strategies. We also assign estimates of stumpage values and their costs to the volume yields indicated in Appendix Tables 20–23, and then compare the resulting timber values. Methods for testing the economic effectiveness of managing a particular stand are available elsewhere (Leak 1980).

Hardwood Diversity

In any discussion of northern hardwoods and associated types, we must first emphasize their diversity. Each species has its own package of characteristics as to strength, workability, appearance, and appeal. Market prices attest to this and tend to differentiate relative values among species.

Eastern hardwood stands also are diverse in product potential. Figure 10 depicts a hierarchy of relative product values, along with a general woods-run volume distribution that is typical of many eastern hardwood stands. Although the actual values vary from one stand to another because of species and size mix, logging conditions, and markets, the relative value differences among products often are large (DeBald 1981).

Timber size and quality are especially important in northern hardwoods. Figure 11 shows the relative values of trees by both diameter and butt-log grade. The increased value through increased size suggests concentrating growth on selected fast-growing crop trees. The large differences in tree values from one butt-log grade to another indicate the importance of concentrating growth on trees that are likely to impove in grade.

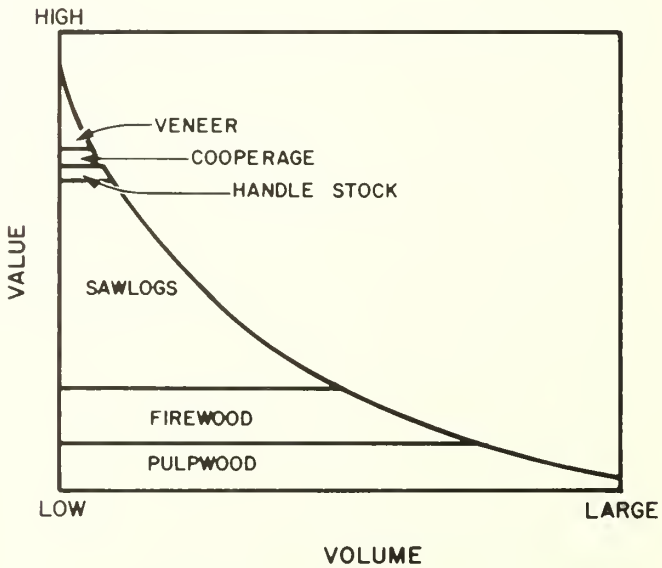

Figure 10.—Typical value/volume hierarchy, eastern hardwood stands.

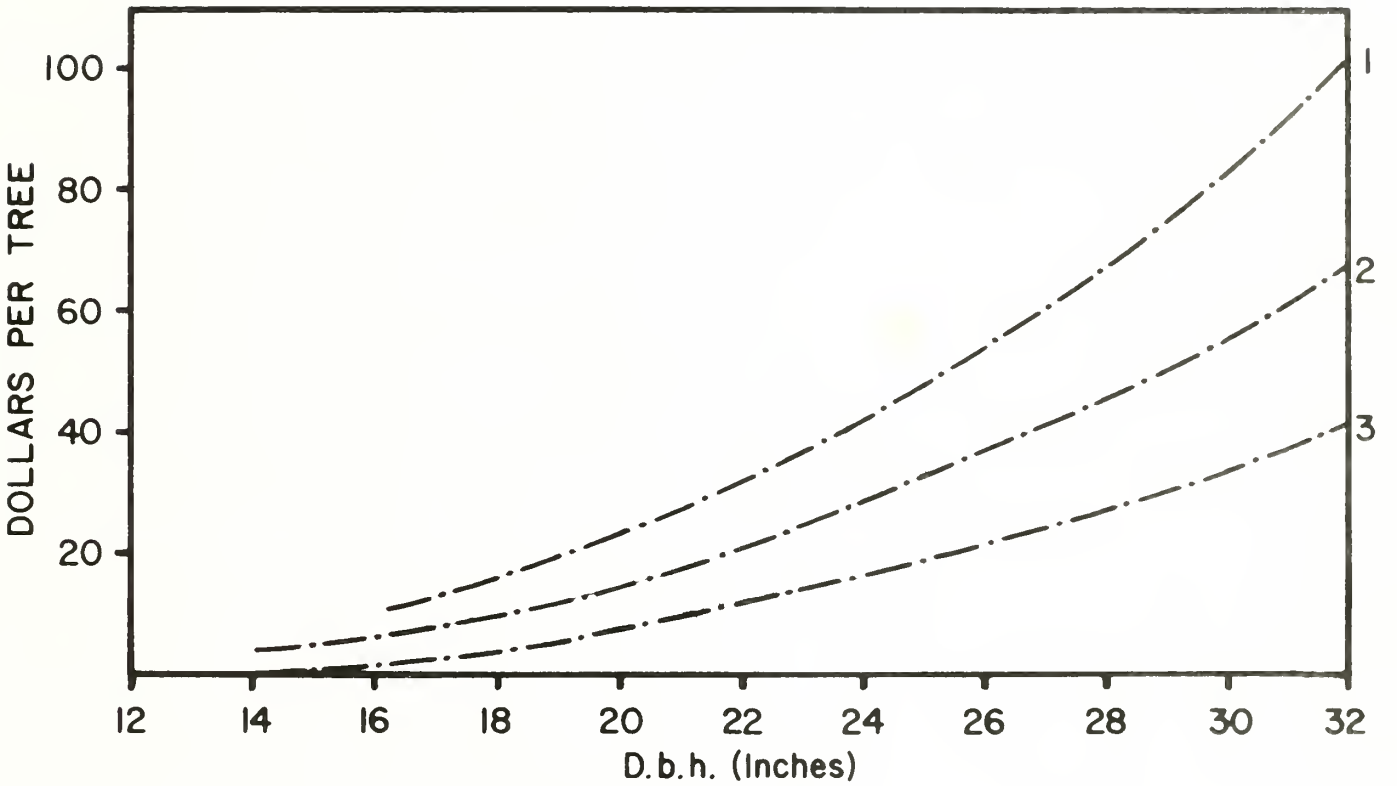

Figure 11.—Relative values of two-log hard maple trees, by butt-log grade.

Potential Timber Values

The biological recommendatons in this silvicultural guide capitalize on the diversities mentioned through the manipulation of species mix, tree size, timber quality, and product objectives. But are higher timber values worth waiting for? Are they worth working for? The short answer is: probably. The long answer depends on a number of factors.

One factor concerns the anticipated timber yields themselves. As shown earlier, we can expect timber yields sooner through silvicultural activities. We also can expect the overall volume yields to be greater. But in order to test the economic effectiveness of our silvicultural guidelines, we need to assess the possible dollar returns from those physical yields, along with their costs.

We must first consider the product potential of a stand with and without silvicultural treatment (Table 13). We would, for example, expect a low product potential in unmanaged stands and higher potentials in managed stands, depending on our efforts to develop those potentials. In Table 13, product distribution A represents a typical unmanaged northern hardwood stand (Filip and Williams 1968). Distributions B, C, and D represent a range of improved product mixes that might be expected through the application of silvicultural guidelines, and reflect an upgrading of timber quality through thinnings.

Table 13.—Assumed percentages of sawtimber volume

Product	Product distribution			
	A	B	C	D
Veneer	2	4	6	8
Sawlogs				
High quality	3	6	9	12
Medium quality	40	45	50	55
Low quality	15	15	15	15
Pallet stock	40	30	20	10

Next, we must assign dollar values to potential products. Recent stumpage prices in New Hampshire indicate a wide range in values by product class and highlight the value premiums for higher value products (Table 14). They also point to the importance of encouraging the development of high-value species.

To evaluate the development of quality over long and varying timespans, we should include price-change expectations in our valuations. Let's use real rates of price change—rates over and above inflation. Using real prices eliminates the need to make an additional guess at expected long-run inflation rates and reflects the fact that hardwood lumber-price trends often exceed inflation rates. Let's use the stumpage prices in Table 14 for a base and project them to increase in real value as follows:

Log quality	*Real rate of increase (%)*
Veneer and high	3
Medium	2
Low	1
Pallet stock	0.5

We can then assign estimates of dollar values to both the thinnings and the standing volumes shown in Tables 20–23—in real terms. The results will portray the benefits of quality development and our expectations of how silvicultural treatments can enhance the development of quality.

But every benefit has its cost. We need, then, to also consider the costs of maintaining and managing a timber stand—again, over long and varying timespans. So, let's assume an annual real cost of $1 per acre for such things as property taxes and maintaining boundaries. Although the annual cost is common to each of the management strategies, the total costs will vary depending on the timespans that the management strategies cover. Let's assume, further, that consulting forester fees account for 10 percent of timber-sale proceeds, a 30-percent income tax bracket, and capital gains treatment of 40 percent.

Table 14.—Recent typical sawtimber stumpage prices (adapted from Engalichev 1984)

Product class	White ash	Hard maple	Yellow birch	White birch	Red oak	Other
			Dollars/M bf			
Veneer	135	90	115	110	170	45
Sawtimber						
High quality	120	90	105	85	135	40
Medium quality	90	65	80	65	100	30
Low quality	70	50	65	55	75	25
Pallet stock	25	25	25	25	25	25

Net Present Values

But we also must consider the time value of money. For most of us, a dollar in hand today is worth more than a dollar to be received (or spent) 5 years from now. How much more depends on the rate of return (cost of capital) that we assume. The values in Table 15, for example, are net present values, the result of discounting expected net future values and expected future costs all back to year zero at a rate of 4 percent, then subtracting the discounted costs from the discounted values. Discounting to year zero converts varying timeframes to one common point in time and allows us to analyze stand-value development over time. The resulting net present values express all amounts in equivalent terms—today's dollars at time zero.

Comparison of different thinning regimes suggest that silvicultural activities aimed at improving product mix can result in a substantial increase in value yields (Table 15). The more we improve the potential product mix, the greater the value yield.

Although much of the increased value results from improved product mix, the timing of value yields also is important. The time required to reach a given mean stand diameter is considerably shorter with management than it is without management. Holding costs, then, are lower. But more important, the discounting period for managed stands of a given mean diameter are much shorter than they are for unmanaged stands of the same diameter. Note that even if product mix were not improved by thinnings (Table 15, Column A), the net present values of managed stands are much higher than those for unmanaged stands. The time value of money is extremely important.

The value of timber removed in thinnings also is important. The cash flows that they generate add greatly to the overall value yields from managed stands. In many managed stands, the net present value of timber sold from thinnings amounts to almost as much as the net present value of the standing timber.

The prospect of building up higher timber values faster, combined with cash flows from thinnings, suggests that managing northern hardwoods can be worthwhile. Depending on the degree of improvement in product mix, the value yields of managed stands can be dramatically higher than those of unmanaged stands.

Table 15.—Estimates of net present value for northern hardwoods by thinning regime[a] and product distribution (based on projected real stumpage prices and 4-percent discount rate)

Mean d.b.h. (inches)	Stand age	Product distribution[b] A	B	C	D
	Years		*Dollars*		
			9-Inch Thinning		
8	67	5	12	19	25
10	83	20	33	46	58
12	98	35	54	74	93
14	110	42	66	89	113
16	125	35	58	81	104
18	142	32	55	78	101
			7-Inch Thinning		
8	64	14	23	32	41
10	76	36	52	68	85
12	90	50	73	95	118
14	101	66	96	125	155
16	114	60	89	118	147
18	128	57	86	116	145
			Quality-Line Thinning		
8	61	20	30	40	50
10	72	48	67	86	105
12	83	66	92	117	143
14	95	77	108	139	170
16	107	75	108	140	173
18	119	69	101	133	165
			Unmanaged		
8	67	5	—	—	—
10	87	11	—	—	—
12	114	6	—	—	—
14	157	-6	—	—	—
16	196	-15	—	—	—
18	230	-19	—	—	—

[a] Thinnings beginning at 9, 7, and approximately 5 (Quality line) inches mean stand diameter, and no thinning (unmanaged), and with yield schedules as shown in Tables 20–23.

[b] See Table 13 for product distributions.

Rate of Return

As an alternative to net present value, we might consider a rate of return analysis of timber management strategies. The internal rate of return (IRR), for example, is the compound rate of interest that equates the present value of expected future returns with the present value of expected future costs. It is the interest rate at which net present value is zero.

Using the same timber value and cost information that we used to estimate net present values, we estimated the internal rates of return for the same management strategies and product distributions. We found that we might expect managed northern hardwood stands to yield real rates of return that range from 5 to 8 percent (Table 16); and that unmanaged northern hardwoods might, at best, yield rates below 5 percent.

Note that the IRR cited are real rates. They do not include the effects of inflation. We can, though, approximate nominal or market rates by adding our inflation expectations to

Table 16.—Estimates of real rate of return for northern hardwoods by thinning regime[a] and product distribution (based on real stumpage prices)

Mean d.b.h. (inches)	Stand age	Product distribution B	C	D
	Years		*Percent*	
			9-Inch Thinning	
8	67	5.0	5.3	5.6
10	83	5.5	5.8	6.1
12	98	5.7	5.9	6.2
14	110	5.7	6.0	6.2
16	125	5.6	5.8	6.0
18	142	5.4	5.7	5.9
			7-Inch Thinning	
8	64	5.7	6.2	6.5
10	76	6.4	7.0	7.3
12	90	6.5	7.0	7.3
14	101	6.5	6.8	7.0
16	114	6.3	6.8	7.0
18	128	6.2	6.5	6.7
			Quality-line Thinning	
8	61	6.2	7.1	7.5
10	72	6.8	7.2	7.5
12	83	6.9	7.5	7.8
14	95	6.9	7.4	7.7
16	107	6.7	7.0	7.3
18	119	6.6	7.0	7.2

[a] Thinnings beginning at 9, 7, and approximately 5 (Quality line) inches mean stand diameter, and with yield schedules as shown in Tables 20–23.

the real rates.[2] For example, if we expected a 7 percent rate of return over over a span of years, along with an average inflation rate of 4 percent, the nominal IRR would be approximately 11 percent. The tough (if not impossible) part of making the conversion is trying to predict future inflation rates.

The differences in possible value yields, with and without management, seem wide enough to demonstrate the economic effectiveness of adopting silvicultural guidelines in the management of northern hardwood forests generally, and to warrant taking a closer look at the management potentials of individual stands, specifically.

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[2]Actually, we would use the formula $(1+n)=(1+r)^*(1+i)$ when n, r, and i are the decimal equivalents of the nominal (or market), real, and inflation rates, respectively. Conversions between real and nominal rates should be made by multiplying and dividing, not by adding and subtracting.

Appendix

Table 17.—Cumulative percent crown cover for sugar and red maples, yellow and paper birches, 10-factor prism

D.b.h. (inches)	Tree count											
	1	2	3	4	5	6	7	8	9	10	11	12
2	59	119										
4	28	57	85	114								
6	21	41	62	82	103							
8	17	34	51	68	84	101						
10	15	30	44	59	74	89	103					
12	13	27	40	53	67	80	93	106				
14	12	24	37	49	61	73	86	98	110			
16	11	23	34	45	57	68	80	91	102			
18	11	21	32	43	54	64	75	86	96	107		
20	10	20	30	40	50	60	70	80	91	101		
22	10	19	29	38	48	57	67	76	86	96	105	
24	9	18	27	36	45	54	64	73	82	91	100	109
26	9	17	26	35	43	52	61	69	78	87	95	104

Table 18.—Cumulative percent crown cover for white ash, white pine, red spruce, balsam-fir, and hemlock, 10 factor prism

D.b.h. (inches)	Tree count																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
2	32	64	95	127														
4	15	30	45	60	74	89	104											
6	11	21	32	43	54	64	75	86	96	107								
8	9	18	27	36	44	53	62	71	80	89	98	107						
10	8	16	24	32	40	47	55	63	71	79	87	95	103					
12	8	15	22	30	38	45	52	60	68	75	82	90	98	105				
14	7	14	20	27	34	41	48	54	61	68	75	82	88	95	102			
16	6	13	20	26	32	39	46	52	58	65	72	78	84	91	98	104		
18	6	13	19	25	32	38	44	50	57	63	69	76	82	88	94	101	107	
20	6	12	18	24	30	37	43	49	55	61	67	73	79	85	92	98	104	110
22	6	12	18	24	30	35	41	47	53	59	65	71	77	83	88	94	100	106
24	6	12	17	23	29	35	41	46	52	58	64	70	75	81	87	93	100	104
26	6	11	17	23	28	34	40	46	51	57	63	68	74	80	86	91	97	103

Table 19.—Cumulative percent crown cover for beech, 10-factor prism

D.b.h. (inches)	Tree count						
	1	2	3	4	5	6	7
2	52	105					
4	30	59	89	118			
6	23	47	70	93	117		
8	21	41	62	82	103		
10	19	38	57	76	95	114	
12	18	36	54	72	90	107	
14	17	34	51	69	86	103	
16	17	33	50	67	83	100	
18	16	33	49	65	81	98	114
20	16	32	48	64	80	95	111
22	16	31	47	63	78	94	110
24	15	31	46	62	77	93	108
26	15	30	46	61	76	91	107

Definitions of Simulated Thinning Regimes

1. No Thinning: Stands were allowed to develop naturally.

2. Quality-line Thinning (Fig. 1): Up to 6 inches mean stand diameter, stands were thinned once to 80 ft^2 of basal area. Above 6 inches mean stand diameter, stands were thinned to B line whenever the basal area reached 30 ft^2 above the B line (approximately 2/3 the way from B line to A line)

3. 7-inch Thinning: Stands were thinned to B line after mean stand diameter reached 7 inches and whenever the basal area exceeded the B line by 30 ft^2

4. 9-inch Thinning: Stands were thinned to B line after mean stand diameter reached 9 inches and whenever the basal area exceeded the B line by 30 ft^2

All runs began at 4.0 inches mean stand diameter, 91 ft^2 of basal area per acre, and ages of 25, 30, and 35 years, respectively, for site indices 70, 60, and 50 feet (site index for sugar maple at breast-height age 50). Stands were grown to 18.0 inches mean stand diameter. Quality I has sawtimber potential; quality II is pulp potential or cull.

Table 20.—Residual volumes per acre, by species and quality class (I and II), for no thinning and site index 60

Mean d.b.h. (inches)	Age	Residual basal area	White ash		Sugar maple		Yellow birch		Paper birch		Other		Combined		
			I	II	I	II	I	II	I	II	I	II	I	II	A
	Years	*Ft^2*	*Board feet/acre*												
4	30	91	—	—	—	—	—	—	—	—	—	—	—	—	—
6	49	102	—	—	—	—	—	—	—	—	—	—	—	—	—
8	67	107	49	49	646	441	742	484	357	285	289	218	2083	1477	3560
10	87	110	98	98	1295	883	1487	969	441	352	580	437	3901	2739	6640
12	114	113	163	163	2167	1478	2488	1622	—	—	971	731	5789	3994	9783
14	157	116	218	218	2890	1970	3318	2164	—	—	1295	975	7721	5327	13048
16	196	118	221	221	2936	2002	3371	2198	—	—	1317	991	7845	5412	13257
18	230	119	224	224	2972	2026	3412	2225	—	—	1332	1003	7940	5478	13418

Table 21.—Residual and cumulative thinned[a] volume per acre for Quality-line thinning and site index 60

Mean d.b.h. (inches)	Age	Residual basal area	White ash				Sugar maple				Yellow birch				Paper birch				Other				Combined					
			Thin		Residual		Thin		Residual		Thin		Residual		Thin		Residual		Thin		Residual		Thin			Residual		
			I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	A	I	II	A
	Years	*Ft²*	*Board feet/acre*																									
4	30	91	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	48	93	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
8	61	66	23	—	58	—	305	—	756	—	319	—	783	—	119	—	293	—	129	—	321	—	895	—	895	2211	—	2211
10	72	91	23	—	153	—	305	—	1910	—	319	—	1840	—	119	—	728	—	129	—	840	—	895	—	895	5471	—	5471
12	83	85	73	—	213	—	927	—	2695	—	918	—	2454	—	357	—	802	—	405	—	1211	—	2680	—	2680	7375	—	7375
14	95	75	162	—	268	—	2060	—	3408	—	1950	—	3100	—	546	—	135	—	915	—	1538	—	5633	—	5633	8449	—	8449
16	107	91	162	—	332	—	2060	—	4217	—	1950	—	3836	—	546	—	—	—	915	—	1904	—	5633	—	5633	10289	—	10289
18	119	78	269	—	283	—	3424	—	3590	—	3191	—	3266	—	546	—	—	—	1530	—	1621	—	8960	—	8960	8760	—	8760

[a] Six thinnings at mean d.b.h. 5.2, 6.1, 7.8, 10.2, 13.1, and 16.5 inches.

Table 22.—Residual and cumulative thinned[a] volume per acre for 7-inch thinning and site index 60

Mean d.b.h. (inches)	Age	Residual basal area	White ash				Sugar maple				Yellow birch				Paper birch				Other				Combined					
			Thin		Residual		Thin		Residual		Thin		Residual		Thin		Residual		Thin		Residual		Thin			Residual		
			I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	A	I	II	A
	Years	*Ft²*	*Board feet/acre*																									
4	30	91	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	49	102	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
8	64	79	—	22	69	17	—	272	885	—	—	297	965	—	—	153	416	—	—	129	387	—	—	873	873	2722	17	2739
10	76	76	34	50	120	—	435	272	1550	—	459	297	1550	—	206	153	684	—	195	130	700	—	1329	902	2231	4604	—	4604
12	90	67	101	50	170	—	1305	272	2227	—	1318	297	2202	—	440	153	392	—	594	130	1020	—	3758	902	4660	6011	—	6011
14	101	88	101	50	302	—	1305	272	3949	—	1318	297	3884	—	440	153	—	—	594	130	1822	—	3758	902	4660	9957	—	9957
16	114	76	201	50	261	—	2612	272	3415	—	2605	297	3595	—	440	153	—	—	1197	129	1575	—	7055	901	7956	8610	—	8610
18	128	91	201	50	311	—	2612	272	4077	—	2605	297	4010	—	440	153	—	—	1197	129	1881	—	7055	901	7956	10279	—	10279

[a] Four thinnings at mean d.b.h. 7.1, 9.1, 11.7, and 14.9 inches.

Table 23.—Residual and cumulative thinned[a] volume per acre for 9-inch thinning and site index 60

Mean d.b.h. (inches)	Age	Residual basal area	White ash				Sugar maple				Yellow birch				Paper birch				Other				Combined					
			Thin		Residual		Thin		Residual		Thin		Residual		Thin		Residual		Thin		Residual		Thin			Residual		
			I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	A	I	II	A
	Years	*Ft²*	*Board feet/acre*																									
4	30	91	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	49	102	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
8	67	107			49	49	—	—	645	441	—	—	742	484	—	—	357	285	—	—	—	—	—	—	—	2078	1477	3555
10	83	77	1	69	113	—	7	631	1545	—	9	693	1700	—	4	418	689	—	3	312	699	—	24	2123	2147	4746	—	4746
12	98	97	1	69	234	—	7	631	3177	—	9	693	3498	—	4	418	145	—	3	312	1444	—	24	2123	2147	8498	—	8498
14	110	89	63	69	279	—	862	631	3795	—	950	693	4177	—	126	418	—	—	393	312	1726	—	2394	2123	4517	9977	—	9977
16	125	77	157	69	243	—	2126	631	3315	—	2342	693	3650	—	126	418	—	—	968	312	1509	—	5719	2123	7842	8717	—	8717
18	192	93	157	69	294	—	2126	631	3992	—	2342	693	4395	—	126	418	—	—	968	312	1817	—	5719	2123	7842	10498	—	10498

[a] Three thinnings at mean d.b.h. 9.1, 11.6, and 14.7 inches.

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A practical guide to the management of northern hardwoods for timber production in New England and New York. Both even-age and uneven-age management are considered, and specific treatments are prescribed for a range of stand conditions and management objectives.

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NE-RP-604

Variations in Productivity and Performance in Grade Lumber Industries in Kentucky, Pennsylvania, and West Virginia—1982

Gilbert P. Dempsey

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Abstract

Hardwood sawmills are the basic link between a valuable and growing resource and the domestic and foreign users of fine hardwood lumber products. Their effectiveness is crucial to the growth and development of wood industries among locales, states, regions, and countries. Productivity ratios, structural factors, and other indicators of economic performance were used to measure the relative productive efficiency of the grade hardwood lumber industries (sawmills and planing mills) in Kentucky, Pennsylvania, and West Virginia. Their economic performance was high compared to the predominantly softwood U.S. lumber industry in 1982. Among the states, labor productivity was greatest in Kentucky; product prices received were highest in Pennsylvania; but West Virginia's sawmills were the most economically efficient. Despite undercapitalization, the industries' latent capacity and efficiency potential provide the base and make the prospect for socially desirable economic development a highly viable option in all three states.

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Introduction

The hardwood sawmill industry[1] is the basic link between a valuable and growing resource and domestic and foreign users of hardwood lumber products. The hardwood lumber industry is competitive, allowing cost-reducing efficiencies attained by the lumber industry to flow backward and forward in the distribution system: backward to loggers and landowners and their suppliers, forward to secondary manufacturers and ultimately the consumer. To a significant degree, the economic value and development potential of the resource, as well as the operating margins and competitiveness of industrial users of lumber products, are affected directly by the efficiency of supply from the primary timber breakdown process—the sawmill. Therefore, a better understanding of the factors that influence sawmill efficiency will improve the competitiveness of sawmill operations and indirectly benefit local communities, landowners, and consumers of hardwood products.

This paper presents an analysis of the current operating and financial structure, performance, and productivity of the lumber industries in Kentucky, Pennsylvania, and West Virginia—three of the Nation's more important Appalachian and northern hardwood-producing states. These states do not produce a significant amount of softwood lumber, which allows direct examination of the hardwood industry when using secondary data. With some exceptions, the natural resource bases of the three states are similar; but they differ in labor markets, product markets, levels of secondary wood product manufacturing, and other factors that influence sawmill structure and performance. This paper provides baseline information and findings to support specific actions for economic improvement.

The Data

The primary data source for the study was the most recent (1982) Census of Manufactures—the Industry and Geographic Series, which is both the major and most complete and consistent source of facts about the structure and functioning of the Nation's manufacturing establishments. These sources were supplemented with data from the U.S. Department of Commerce, Current Industrial Reports; U.S. Department of Labor, Bureau of Labor Statistics; state and USDA Forest Service documents; the general literature, knowledgeable industry personnel; and my own knowledge of lumbering in each of the three states gained over the many years of association with the industry. However, as with any secondary information, there were data limitations.

A major criticism of Census data is that production figures for hardwood lumber appear to underreport actual production levels. Lumber consumption figures developed by Cardellichio and Binkley (1984) suggest that hardwood lumber production was underreported by approximately 20 percent in 1979. And state forestry personnel generally estimate an even larger difference. I agree with this criticism but contend that changes in production as reported by the Census do reflect changes in actual production levels.

Too, the reader must be aware that 1982 was an economic recessionary year for the general economy. The primary overt effect of the economic recession on the lumber industries in the three states was a decrease in demand, which resulted in relatively lower than normal quantities of inputs, outputs, and prices of outputs. And, quite probably, the recession was a partial cause of fewer mills operating in each of the states in 1982 than in 1977. Even though each state's lumber industry may have been affected differently by the recession, the comparability of the operational and performance measures is not compromised. In fact, this comparison may provide additional insight into the relative strengths of the lumber industry in each of the three states in terms of their response to the recession.

Economic Setting

Lumber was one of the earliest and most important manufacturing industries in Kentucky, Pennsylvania, and West Virgina. But with the onset of the Industrial Revolution, other manufacturing segments within each state began to surpass the lumber industry in economic importance (Brown 1958). Today, the grade lumber industry that has evolved remains a positive economic force in its predominately rural localities; it is of prime importance to the sustenance and development of timbering as well as secondary wood and related manufacturing within its respective and neighboring states.

For example, Pennsylvania's lumber industry produced more than 481 MM bf (million board feet) of primary products in 1984 (U.S. Department of Commerce 1985a,b). A conservative estimate of the first-sale contribution of this output to the State's rural economies was about $279 million (U.S. Department of Labor 1983, 1985). These receipts averaged over $744,000 for each of the 375 operating establishments surveyed.

To the extent that these monies were spent within Pennsylvania's local economies for products and services, and lumber products were further manufactured within the State, the turnover or multiplier effect of this income was

[1] The lumber-producing sawmill industry (SIC 2421, Sawmills and Planing Mills, General), as defined by the 1982 Census of Manufactures, comprises operating manufacturing establishments primarily engaged in the sawing of lumber from logs and bolts or the resawing of cants and flitches into lumber and cut stock, and establishments that saw railroad ties, lath, and miscellaneous lumber-like products.

substantial. This is especially true of sawmills since a large proportion of the industry's value received for products sold is expended for raw materials, supplies, labor, and capital— most of which are locally supplied (91 percent of Pennsylvania's lumber mills' value of shipments is spent for these required inputs). For example, with a multiplier effect of 3 in 1984, Pennsylvania's lumber industry would have generated expenditures of $837 million worth of economic activity at the state level, averaging $2,232,000 per sawmill.

Physical Plant

The Census of Manufactures' survey of the industry provides data on 751 commercial lumber-producing sawmills and planing mills operating in the three states during 1982—375 in Pennsylvania, 195 in Kentucky, and 181 in West Virginia. Included in the survey population were all establishments of multi-unit companies and all single-unit companies in the industry with five or more employees. Further, the Bureau, recognizing that there are many smaller mills within the industry, developed data for these establishments from administrative records and other institutional sources.

The significance of the small lumber mill in these states is evident by the fact that state forest product industry directories report 1,892 operational sawmills located within the tristate area in 1984 (Table 1). Although not necessarily full-time operations, small hardwood sawmills produce a considerable amount of lumber, especially during periods of high demand. And, theoretically, assuming market accessibility and land, labor, and capital resources, these mills could contribute significantly to production given the proper stimulant; for example, substantial and stable price increases for lumber products and/or national emergencies, as occurred in 1941.

Although the Census recognizes the existence of small sawmills within the industry, many of these are family-owned and operated and may not be listed in administrative records. The production at these small mills is, therefore, the most likely source of the underreporting since the industry in each of these states changes slowly. Further, the count and patterns of operations for several years prior to 1982 were essentially the same as those shown in 1984.

Productive Factor Outputs and Performance

The hardwood lumber industry's performance is influenced by many social and economic conditions (Ellefson and Stone 1984). But given access to economic resources and markets, and a viable framework within which to conduct

Table 1.—Number and annual production class of operational sawmills in Pennsylvania, Kentucky, and West Virginia, 1984[a]

Production class (MM bf)	Mills		
	Pennsylvania	Kentucky	West Virginia
		Number	
10 or more	5	5	4
5 to 10	53	17	20
2 to 5	101	73	36
1 to 2	116	83[b]	40
1 MM bf >	275	178	100
500 M bf to 1 MM bf	265	66	45
< 500 M bf + custom mills	428	256	279
All mills	968	500	424

[a]Assumed operational, but may or may not have been in operation during survey year.

[b]Estimate based on Kentucky wood industry directories for prior years and patterns evidenced in Pennsylvania and West Virginia.

Source: Lohr 1985; Thorpe 1984; Warder 1984.

business, the cost structure and output of the industry (firm) are fundamental to its productivity and overall performance. Three of the principal and most useful outputs for measuring the effectiveness of the industry in terms of economic efficiency and socially desired performance are (1) physical products produced, (2) value received for products sold, and (3) value added by the manufacturing process.

Lumber Products Output

Total reported U.S. hardwood lumber production in 1982 amounted to 5.1 billion board feet, of which about 17.9 percent was produced in Kentucky, Pennsylvania, and West Virginia. However, compared with the previous 5 years, hardwood lumber production was lower in 1982 for all three states, as well as for the United States.

In 1982, the tristate sawmill industry produced 938 MM bf of lumber products, of which 96.7 percent was hardwoods (Table 2). This output relationship was almost the opposite of that for the U.S. lumber industry, which was 83.1 percent softwoods and 16.9 percent hardwoods in 1982. Total hardwood lumber production per establishment averaged 1.249 MM bf, or about one-fourth as much per establishment as the predominantly softwood U.S. lumber industry. This reflects the effect of the traditionally larger capacity of output of softwood mills due to both the type of product—principally construction lumber of the less dense coniferous species versus grade lumber of the denser deciduous species—and differences in quantity and quality of the inputs, especially capital and technology.

Among the states. In 1982, Pennsylvania's sawmills led the tristate area in total lumber production with 416 MM bf, 96.6 percent of which was hardwoods. Kentucky's lumber output was the second largest at 270 MM bf, but less than two-thirds that of Pennsylvania. And West Virginia's lumber output, normally higher than Kentucky's, was only three-fifths that of Pennsylvania, or 252 MM bf in 1982. Like Pennsylvania, most of the lumber output in both Kentucky and West Virginia was composed of hardwoods—95.9 percent in Kentucky and 97.6 percent in West Virginia.

Kentucky's lumber industry had the second largest average volume of output of lumber per mill per year at 1.385 MM bf, but it had the highest average output per employee and production hour worked—significantly higher than Pennsylvania and West Virginia. Kentucky's average output per employee was 135.0 M bf (thousand board feet), 12.5 percent higher than West Virginia's and 7.1 percent more than Pennsylvania's.

Data are not available to explain conclusively the large differences in gross physical output per employee between Kentucky's sawmill industry and those of West Virginia and Pennsylvania. However, the most probable partial explanations are:

1. Nature of output: Kentucky ranked sixth among the Nation's top 10 users of hardwood lumber for pallet production in 1984 and held that approximate position in 1982. It also had a strong treating industry. Consequently, compared with Pennsylvania and West Virginia, Kentucky's lumber mills likely produced a higher proportion of industrial products. Such stocks require somewhat less time to process than grade lumber outputs.

2. Nature of physical plant: Based on output, Kentucky's lumber industry has shown signs of expanding over the past 10 to 15 years (Schallau et al. 1985); thus, its

Table 2.—Lumber products output by tristate and U.S. lumber industries, by area (SIC 2421), 1982

Area	Total lumber output by:		Average lumber output by:	
	Hardwood	Softwood	Establishment	Employee
	MM bf		*MM bf*	M bf
Pennsylvania	402	14	1.109	126.1
West Virginia	246	6	1.392	120.0
Kentucky	259	11	1.385	135.0
Total/mean	907	31 < >	1.249	126.8
United States	5,061	24,949	4.751	227.5

Source: U.S. Department of Commerce, Bureau of the Census 1984a,b,c,d, 1985 a,b.

lumber mills may have a lower ratio of labor to undepreciated capital assets than either Pennsylvania or West Virginia. This would indicate the operation of newer and perhaps more productive capital plant, machinery, and equipment mixes.

Value of Products Sold

The tristate sawmill industry received $382.8 million from lumber products sold in 1982; this represents about 3.8 percent of the total value of lumber shipped by the U.S. lumber industry (Table 3). Receipts averaged $510,000 per establishment, or about 32 percent of that received by the average U.S. sawmilling establishment. More telling, however, is that tristate industry receipts per unit of product sold averaged $408 per M bf of product—only 21.8 percent higher than that received by the predominantly softwood U.S. sawmill industry. Although the difference in receipts reflects a higher unit value for the hardwood output, it is less than might be expected given the prevailing market prices of that period.

Among the states. Pennsylvania's sawmills, with the largest output and highest prices received per unit, led in total value of shipments with $193.1 million in 1982—over twice that of West Virginia's shipments, valued at $95.5 million, and Kentucky's, $94.2 million. West Virginia mills, due to a smaller number but larger average output per mill, led in value of shipments with $528,000 per establishment. This was only slightly higher than Pennsylvania's $515,000 receipts per establishment, but 9.3 percent greater than Kentucky's $483,000 per unit.

In all other breakdowns of values received, however, Pennsylvania's sawmill industry led those in West Virginia and Kentucky: Pennsylvania's firms received an average of $464 per M bf for their lumber products sold and shipped compared to West Virginia's $379 per M bf and Kentucky's $349 per M bf. This tends to support earlier evidence that Pennsylvania is milling higher valued logs, the probable result of a larger proportion of higher valued species such as red oak. Other viable explanations for the higher output prices received by Pennsylvania sawmillers could be: (1) the innate strength of the State's internal market for lumber products; (2) a higher proportion of unmodified lumber resales; (3) more direct marketing; (4) more specialized services being provided by the industry, such as planing, drying, and milling-to-order; and, perhaps, (5) more vertical integration in the industry, thus allowing cost-center financial accounting adjustments.

The differences in prices received between West Virginia's and Kentucky's industries were small and probably can be explained more by log size, quality, and species than by either specialized or secondary processing. A larger proportion of Kentucky's lumber products is thought to be moving into the growing industrial product markets—such as the treating and pallet stock industries, which use the mixed hardwoods and require less processing than grade lumber.

Value Added by Manufacture

The value added by manufacturing measure is considered the best general indicator of a firm's or industry's economic performance (Ellefson and Stone 1984). The dollar value added by manufacture is that portion of the value of shipments (total value received for products sold or otherwise transferred) that remains after deducting total material costs inputed into the production process. It is this portion of the receipts for products sold that is available for payments to labor, capital, rents, and profits.

Table 3.—Value received from lumber shipments by tristate and U.S. lumber industries, by area (SIC 2421), 1982

Area	Total	Value of shipments by:		
		Plant	Employee	Thousand board foot
		Dollars		
Pennsylvania	193,100,000	515,000	58,500	464
West Virginia	95,500,000	528,000	45,500	379
Kentucky	94,200,000	483,000	47,100	349
Total/mean	382,800,000	510,000	51,700	408
United States	10,065,200,000	1,593,600	76,300	335

Source: U.S. Department of Commerce, Bureau of the Census 1984a,b,c,d, 1985a,b, 1986.

In 1982, the Kentucky, Pennsylvania, and West Virginia sawmill industries earned $139 million over and above the cost of materials, or about 4.3 percent of the total value added by the U.S. lumber industry (Table 4). Value added by tristate mills averaged 36.3 percent of their total value of shipments compared to 32.2 percent for the United States—which indicates a relatively lower cost for materials than that experienced by the softwood-dominated U.S. lumber industry.

Value added for the tristate lumber industry averaged $148 per M bf compared to $108 per M bf for the Nation's sawmills, indicating a more effective performance per unit of output. However, due to the differences in physical output, the tristate average value added per employee, production worker, and production worker hour were below that of the U.S. industry by 23.5, 23.6, and 18.8 percent, respectively.

Among the states. West Virginia's lumber industry earned the highest average value added among the three states, which, at $157 per M bf, was 23.6 percent higher than Kentucky's earnings but only 0.6 percent higher than Pennsylvania's. As a consequence of having the highest value added per M bf combined with the largest average output per mill, West Virginia had the largest dollar volume of value added per mill at $219,000, 24.4 percent greater than Kentucky's average sawmill, and 26.6 percent larger than that earned by Pennsylvania's mills.

However, Pennsylvania, due primarily to its substantially higher value of shipments per unit of product, led both West Vriginia and Kentucky in value added returns per employee by at least 5.9 percent. Overall, though, West Virginia's sawmill industry had the best performance in terms of value added—41.5 percent of its value of shipments compared to 36.5 percent for Kentucky and 33.7 percent for Pennsylvania.

Productive Factor Inputs and Performance

A statement of inputs is necessary not only to measure but to understand an industry's operating cost structure and performance. More important, this statement provides an insight into the general economy in which the industry operates and the magnitude of its relationships within and to various segments of that economy. For example, lumber-producing operations affect and are affected by resource and product markets, labor and capital markets, and institutional and other factors both within and well beyond their own immediate operating area. In turn, occurrences in any of these factors that negatively affect inputs also affect output and supply, demand for the product, and ultimately the viability of the firm and industry and all segments of the economy that depend on the industry's output. The factor inputs on which we concentrate are labor, capital, and materials.

Employment

The combined employment in the tristate sawmill industry totaled about 7,400 full-time persons in 1982—3,300 in Pennsylvania, 2,100 in Kentucky, and 2,000 in West Virginia (Table 5). Nationally, this work force represented about 5.6 percent of the lumber industry's total employment but only 3.1 percent of the total lumber product's output in 1982. Assuming similar coefficients of specialization in primary product manufacture, this most likely reflects the relatively higher degree of labor intensity in the production of hardwoods versus softwoods.

Since the demise of the region's virgin timber resources, the small- to medium-size mills have been predominant in the hardwood industry (Simmons 1960). This situation is evident in the tristate hardwood industry and is reflected partially in plant employment. Of the 751 sawmills in Penn-

Table 4.—Value added in lumber production by tristate and U.S. lumber industries, by area (SIC 2421), 1982

Area	Total	Value added by: Plant	Employee	Thousand board foot	Value of shipments
	Dollars				*Percent*
West Virginia	39,600,000	219,000	18,900	157	41.5
Pennsylvania	65,000,000	173,000	19,700	156	33.7
Kentucky	34,400,000	176,000	17,200	119	36.5
Total/mean	139,000,000	185,000	18,800	148	36.3
United States	3,237,500,000	513,000	24,500	108	32.2

Source: U.S. Department of Commerce, Bureau of the Census 1985a,b, 1986.

sylvania, Kentucky, and West Virginia, only 112, or 14.9 percent, employed 20 or more persons per plant in the manufacture of lumber products.

This proportion is substantially below the average for the U.S. lumber industry (24.7 percent) and that for all U.S. manufacturing, where 34.4 percent of the firms employed 20 or more persons. But it is typical in the hardwood lumber industry, where mills tend to be smaller in both physical capacity and output than their counterparts in softwoods. This is due partly to the type of outputs, e.g., emphasis on grade versus construction lumber; the physical differences in breaking down the physiologically denser hardwoods; and lower technology and automation in the smaller hardwood mills.

Too, tristate hardwood lumber mills are smaller than establishments in U.S. "All Manufacturing" due much to the limits imposed by raw material orientation (located close to resource); traditional orientation to one-shift operations, (which may be totally rational due to the cyclic nature of demand for lumber); and the cyclic nature of the market for output (mills must be of a size to minimize risk of a rapidly fluctuating market demand and still maintain stability of operations—especially labor and capital use).

Among the states. West Virginia's industry averaged the most workers per plant and had the largest proportion of total mills employing 20 or more persons (20.1 percent), followed by Kentucky (13.8 percent), and Pennsylvania (12.8 percent). In absolute terms, Pennsylvania had the largest number of mills (48) employing 20 or more people, but the lowest proportion of such plants to its total industry among the three states. This latter measure reflects the disproportionately large number of very small sawmills in Pennsylvania compared to Kentucky or West Virginia.

Fundamentally, the differences in the structure of the industries among the three states are due largely to the structure of the markets for lumber products in each. For example: (1) Pennsylvania has a variety of well-developed but growing internal markets for the full range of hardwood lumber products. Such markets would provide substantially greater market opportunities for mills with smaller than a medium-size output and specialty mills; (2) West Virginia has a limited secondary wood industry and thus must sell most of its output to external markets—and probably more through brokers or other middlemen; (3) Kentucky has a growing internal market for lumber products but still must market most of its production externally. Consequently, both West Virginia and Kentucky would tend to move larger, more homogeneous shipments of lumber products than Pennsylvania.

Labor Force Composition

Table 6 presents the composition of the tristate work force in terms of (1) production workers, or those plant employees (up through the line-supervisor level) engaged in all plant, direct production-related activities; and (2) "nonproduction" employees, or managers above the line-supervisor level and other production support workers, including sales, clerical, technical, professional, and other administrative personnel.

In 1982, the tristate lumber industry employed 7,400 full-time workers, 6,400 (86.5 percent) of whom were production employees. The industry had about the same percentage of production workers as the U.S. lumber industry

Table 5.—Plant employment in tristate and U.S. lumber industries and U.S. All Manufacturing, by area (SIC 2421), 1982

Area	Total employment	Plants with 20 or more employees	Employees per plant
		Number	
Pennsylvania	3,300	48	8.8
West Virginia	2,100	37	11.6
Kentucky	2,000	27	10.3
Total/mean	7,400	112	9.9
United States	131,900	1,557	20.9
U.S. all manufacturing	19,094,100	123,163	53.3

Source: U.S. Department of Commerce, Bureau of the Census 1985a,b, 1986.

but higher percentages than the U.S. lumber and wood products sector (83.2 percent) and U.S. "All Manufacturing" (64.9 percent). This reflects a high production labor intensiveness for both the hardwood and softwood sawmilling firms compared to manufacturing in general, and underlines the relative dearth of nonproduction personnel expertise in the lumber industries compared with most other types of manufacturing.

Among the states. West Virginia's sawmill industry had the highest percentage of total employees (90.4) in the production category—a 9.5 to 1 ratio of production to nonproduction personnel—or about one administrative employee for every 9.5 production line workers. Kentucky and Pennsylvania both had about 85 percent of their total work force in a production worker capacity, and production to nonproduction worker ratios of 5.7 to 1 and 5.6 to 1, respectively.

Even considering the vagaries caused by the rounding of data, West Virginia's ratio of production to nonproduction personnel is quite different from those of Kentucky, Pennsylvania, or the United States. Probable reasons for the difference are: (1) less on-site emphasis on marketing, market development, technical development, and indirect production management activities by individual mills; and (2) a greater reliance on outside establishments for these services.

West Virginia had the lowest ratio of management to labor within the tristate lumber industry and was about 50 percent lower than the ratio for the U.S. lumber industry. Under such circumstances, the mill manager could pay only fleeting attention to the firm's transactional requirements. And since there is no indication that the cost of purchased services in West Virginia's sawmills are disproportionate to that of the other two states or the U.S. lumber industry, it suggests that these services, if being received, come from outside the establishment from other firms either within or outside of the State.

In fact, both situations probably are applicable; that is, medium to larger mills that are owned by corporations or other entities located elsewhere probably receive the more critical administrative support services from their respective headquarters rather than having support personnel at the production site. In such circumstances, the mill personnel on the production site can give their full attention to the production process. Too, many of the smaller independent mills probably are receiving much of the more critical nonproduction services such as market information, technical information, and other professional advice from outside (nonowned) vested-interest sources such as brokers, other middlemen, and suppliers.

The differences in the ratios of production to nonproduction personnel employed by tristate sawmills suggest that, compared to West Virginia, the mills in Kentucky and Pennsylvania probably: (1) had more administrative and/or technical expertise within their on-site staffs; and (2) had greater flexibility (and, possibly, autonomy) in making production, marketing, and development decisions; and, thus, (3) placed less reliance on outside sources for critical, nonproduction services. Such differences in operational characteristics have important implications for the development of both private and institutional efforts and strategies to effect structural changes, growth, and development in the industry.

Table 6.—Composition of labor force in tristate and U.S. lumber industries, by area (SIC 2421) and U.S. All Manufacturing, 1982

Area	Employees		
	Production	Nonproduction	Ratio
	Number		
Pennsylvania	2,800	500	5.6 to 1
West Virginia	1,900	200	9.5 to 1
Kentucky	1,700	300	5.7 to 1
Total/mean	6,400	1,000	6.4 to 1
United States	113,900	18,000	6.3 to 1
U.S. all manufacturing	12,400,600	6,693,500	1.9 to 1

Source: U.S. Department of Commerce, Bureau of the Census 1985a,b, 1986.

Production Worker Employment

The number of plant hours worked by production personnel[2] varied significantly between the lumber industries of two of the three states and among all three states and the Nation's industry. The 6,400 production personnel worked 11.6 million plant-hours in the direct production of lumber products in 1982 (Table 7). They averaged 15,400 workhours per mill, or less than one-half that of the average (34,800) worked in the higher capacity U.S. lumber industry.

As a group, the tristate mills averaged operating 7.86 man-years, or 92.5 percent of the production worker man-years available based on the current full-time manpower employed. This represented about 1,294 man-hours per plant less than capacity. Using a conservative estimate of plant production hours (1,960)[3] available per worker-year, the tristate lumber industry was underemployed by almost 1 million production hours in 1982. Downtime could have been due to sickness, accidents, lack of demand, weather, and many other factors. Assuming that downtime could have been prevented, and an average output per production worker hour, the tristate industry could have produced additional lumber products valued at nearly $33 million with the unused 1 million production man-hours.

The typical tristate sawmill production worker was employed 1,813 hours—all less than full-time even when excluding paid lumber-industry holidays and vacation time. Workers averaged about 145 hours less than a full work year per production worker, and 114 hours per person less than the average for the U.S. lumber industry in 1982. The lack of full-time employment over an extended time would be expected to contribute to employee turnover and other labor-related problems within the industry (Wolf 1977).

Among the states. The sawmill production hours worked by individual states were: Pennsylvania, 5.3 million; West Virginia, 3.4 million; Kentucky, 2.9 million—all of which excluded paid vacation time, holidays, and sick leave. Pennsylvania mills operated closest to a full work year by providing an average of 1,893 hours of work per worker, or about 96.6 percent of full-time employment. This was about the same as the "All Manufacturing" average but still less than that provided by the U.S. lumber industry. Pennsylvania averaged 7.19 work man-years per establishment of an available 7.47 man-years—or 96.3 percent of the labor force capacity. With the available labor, Pennsylvania industry lost about 0.19 million production hours of operating time, or about 507 hours per plant.

Kentucky and West Virginia mills operated at an annual average rate substantially less than that of Pennsylvania or the U.S. lumber industry. These states provided 1,706 and 1,790 annual hours of work per production worker, or 254 and 170 hours each less than full-time work. Based on their available production man-hours and current labor force, the Kentucky and West Virginia lumber industries lost about 0.430 million hours of work (2,205 hours per plant) and 0.320 million hours (1,768 per plant) based on their available production hours and current labor force. The industry in Kentucky averaged working 7.6 man-years per establishment of an available 8.71 man-years, or 87.3 percent of capacity of the labor force. The West Virginia lumber industry averaged working 9.59 man-years per plant of an available 10.48 man-years, or 91.5 percent of labor force capacity.

The lack of full-time employment over an extended period could lead to undesirable consequences in the tristate lumber industry, especially in Kentucky and West Virginia. Unless the labor market is of such a nature as to condone the situation, underemployment would be expected to: (1) result in higher than normal labor turnover (Wolf 1973, 1977); (2) lessen a firm's competitive hiring ability in the labor market, especially in employing the desired quality of labor; (3) cause higher overhead costs; and (4) the latter, when combined with the initial lower productivity and higher accident potential of new employees (Wolf and Dempsey 1978), would bring about higher marginal costs per unit of output.

Payroll and Wages

Total employee payroll for the tristate sawmill industry in 1982 was $78.4 million, of which $65.2 million (83.2 percent) went for wages for production workers (Table 8). This included total payments made directly to employees for all plant hours worked, including paid sick leave, holidays, and vacation time.

The proportion of total payroll devoted to production workers was slightly higher than that for U.S. lumber industry (81.8 percent), but substantially higher than that for U.S. lumber and wood products sector (76.3 percent) and U.S. "All Manufacturing" (53.9 percent). Such relatives further reflect the tristate hardwood lumber industry's direct production labor intensiveness, and probable lack of emphasis on transactional activities—marketing, for example.

[2] Production-worker hours are those hours actually worked or paid for at the plant, including actual overtime hours.

[3] A conservative estimate of production worker man-year is 1,960 plant hours per worker.

Table 7.—Production worker employment in tristate and U.S. lumber industries, by area (SIC 2421) and U.S. All Manufacturing, 1982

Area/industry	Hours of production worked	Average hours/ plant	Average hours/ worker
		Number	
Pennsylvania	5,300,000	14,100	1,893
West Virginia	3,400,000	18,800	1,790
Kentucky	2,900,000	14,900	1,706
Total/mean	11,600,000	15,400	1,813
United States	219,500,000	34,800	1,927
U.S. all manufacturing	23,538,300,000	65,700	1,898

Source: U.S. Department of Commerce, Bureau of the Census 1985a,b, 1986.

Table 8.—Labor costs in tristate and U.S. lumber industries, by area (SIC 2421) and U.S. All Manufacturing, 1982

Area	Total payroll	Total wages	Labor cost		Percent wages
			Supplemental[a]	Total	
		Million dollars			
Pennsylvania	38.0	31.0	8.8	46.8	66.2
West Virginia	20.7	17.9	5.5	26.2	68.3
Kentucky	19.7	16.3	4.7	24.4	66.8
Total/mean	78.4	65.2	19.0	97.4	66.9
United States	2,020.2	1,651.7	468.7	2,488.9	66.4
U.S. all manufacturing	379,626.5	204,787.2	80,993.4	460,619.9	44.5

[a] A firm's estimated legal and voluntary costs attributable to all employees and expressed as percent of total payroll.

Source: U.S. Department of Commerce, Bureau of the Census 1984a,b,c,d, 1986.

These factors differed substantially among the three states. Pennsylvania and Kentucky had similar proportions of total payroll going to wages—81.6 and 82.8 percent. But West Virginia had 86.5 percent of its payroll devoted to wages, which is consistent with its greater percentage of production versus nonproduction employees.

Supplemental labor costs. In addition to payroll costs, supplemental labor costs, or those costs attributable to the employment of all human capital in addition to wages and salaries, were estimated for the tristate lumber industry for 1982.[4] These costs include (1) *legally required payments*—those required by state or Federal statutes such as Social Security, Unemployment Compensation, and Workmen's Compensation; and (2) *payments for voluntary programs* not specifically required by legislation—such as life insurance premiums, premiums for supplemental accident and sickness insurance, pension plans, supplemental unemployment compensation, welfare plans, stock purchase plans, and deferred profit-sharing plans. They exclude such company-sponsored perquisites such as cafeterias, in-plant medical services, free parking, employee uniforms, etc.

Supplemental labor costs for the tristate sawmill industry totaled $19 million in 1982, or 24.2 percent of the total payroll compared with 23.2 percent for the U.S. industry. Assuming that the distribution of these costs was similar to the average for the U.S. lumber industry, legally required costs amounted to 48.9 percent and voluntary costs to 51.1 percent of the total supplementary labor costs.[5]

Among the individual states, Pennsylvania and Kentucky had similar proportions of total payroll devoted to supplemental labor costs, 23.2 and 23.7 percent. In effect, these added labor charges increased the average cost per employee over payroll by $2,667 in Pennsylvania and $2,350 in Kentucky. Pennsylvania's total dollar cost was higher due to a higher annual wage per employee. West Virginia had an estimated 26.7 percent of its lumber industry payroll paid out in supplemental labor costs; this was substantially higher than in Pennsylvania, Kentucky, or the U.S. industry average. West Virginia's added cost per employee was $2,619, or about the same as the total contribution per employee in Pennsylvania, which was based on a much higher wage.

The West Virginia lumber industry's supplemental labor cost rate was 15.1 percent higher than that of Pennsylvania or the U.S. sawmill industry. This difference resulted in a relatively higher total labor cost, $333 per employee per year. Effectively, this additional cost reduced the industry's net income by $699,300. Had the "extra cost" not been incurred, an additional $699,300 could have been added to total payroll, which would have remained in the local economies. Or another $0.7 million could have been used for capital improvements to increase productivity—which might have resulted in longer term improvements in wages.

Among possible legal and voluntary factors affecting supplemental labor costs are required Federal and state programs, collective bargaining, additional insurance, and labor profit and welfare plans of various types. Although explanatory data are inconclusive, the West Virginia lumber industry may have had higher supplemental labor costs in 1982 due to: (1) Insuring more heavily than operators in Pennsylvania or Kentucky to minimize potentially uninsured liabilities resulting from accidents and sickness. (2) The effective (loaded, based on firm experience) rates for both Workmen's Compensation and Unemployment Compensation may be higher in West Virginia than in Pennsylvania or Kentucky. Either of these explanations would indicate (1) inadequacies in legislation governing the respective social programs; and (2) possible operational inadequacies that discourage stability in the labor force and adequate working conditions. The result of either would be to reduce the funds available and, thus, the flexibility of the State's firms and industry to invest in more effective human and physical capital and operating modes to increase productivity.

Total Labor Costs

With the addition of supplemental labor expenditures to develop total labor costs, the manpower cost relationship among the Pennsylvania, Kentucky, and U.S. industries remained essentially the same. West Virginia showed a disproportionate increase in total labor costs due to its higher percentage of payroll going to legal and voluntary labor costs.

The tristate industry's total expenditures for all employees amounted to about $97.4 million in 1982, with wages to production workers representing 66.9 percent of that amount. This was comparable to the average of 66.4 percent for wages paid by the U.S. sawmill industry during the same period. However, due to lower wages and fewer hours worked, the total annual labor costs per employee for the tristate lumber industry was substantially lower than "All Manufacturing" in each respective state. Viewed as earnings, sawmill labor received 52.9 percent less than "All Manufacturing" in West Virginia, 47.6 percent less in Kentucky, and 41.7 percent less in Pennsylvania.

Among the states. Pennsylvania's total expenditures for labor—including employee salaries, wages, and supplemental costs—were the highest among the three states at $46.8 million in 1982, but it had the lowest proportion going to wages (66.2 percent). The latter was due mostly to the

[4] Estimates based on "All Manufacturing" average within each respective state.

[5] Estimates based on U.S. lumber industry average.

higher relative earnings of nonproduction workers and the lower ratio of production to nonproduction workers in Pennsylvania. Kentucky's total expenditures for labor were slightly more than one-half that of Pennsylvania for 1982, but the percentage going to wages was essentially the same (66.8 percent). West Virginia's total expenditures for labor were slightly higher than Kentucky's, due not to higher average earnings but to a greater number of persons employed.

However, West Virginia's lumber industry had 68.3 pecent of its total expenditures for labor being paid as wages, which was noticeably higher—from 2.2 percent to 3.2 percent higher—than the proportions paid by Kentucky, Pennsylvania, and the United States. The difference is explained by: (1) the higher ratio of production to nonproduction workers employed in West Virginia's lumber industry compared to the other states; and (2) a higher percent of total payroll devoted to supplemental labor costs—15.1 percent higher than Pennsylvania, for example. Still, due to higher wages and salaries, Pennsylvania's mills averaged the highest total labor cost per employee at $14,182 per year, or about 13.7 percent greater than that for West Virginia and 16.2 percent higher than that for Kentucky.

From the employee's perspective, most of the differences in total labor costs per employee between the sawmill industries and "All Manufacturing" in Kentucky, Pennsylvania, and West Virginia were derived from lower earnings per worker. Consequently, on wages alone, general manufacturing in each state had a substantial comparative advantage when competing for labor in the external labor market; and this does not include working conditions, upward mobility potential, and other factors critical to a firm's ability to employ and retain highly productive labor. Thus, assuming the existence of a dual labor market and a mobile labor force, such differences in earnings suggest that the lumber industries of all three states may be bidding in a secondary labor market wherein the training, skills, and work (job) behavior of the labor force is less than ideal for optimum firm efficiency (White 1980).

Capital Expenditures

In recent years, the quantity and quality of capital investments in the production process have become increasingly critical to the firm's efficiency. Table 9 shows the industry's expenditures in 1982 for both new and used machinery, equipment, buildings, and other permanent physical additions and major alterations to plant capacity. Because a limited amount of industry data has been published on the capital structure and expenditures of the tristate sawmill industries, only new and used capital expenditures are presented; the latter were estimated using the U.S. lumber industry average as a proxy.

For the tristate lumber industry, capital expenditures for new and used machinery, equipment, buildings, and other structures totaled $14.22 million in 1982, or 2.6 percent of the total expended by the Nation's lumber industry. Assuming that tristate mills purchased used capital goods at the same rate as the Nation, a ratio of 0.316 to 1, then 75.9 percent (or $10.8 million) of the tristate sawmill industry's total capital expenditures were investments in new physical plant and equipment. The remaining 24.1 percent of total expenditures were for used plant and equipment. If true, this would have been a substantially greater percentage of total expenditures for used machinery, equipment, and physical structures than occurred in each state's "All Manufacturing" sector, as well as in most other segments of their respective lumber and wood products sectors. Further, it opens the question of the occurrence of consolidation in the tristate lumber industry.

The tristate sawmill industry's investments in new capital equipment and physical plant accounted for 28.1 percent of the total new investments made by the area's lumber and wood products sector in 1982. More significantly, however, these industries had investments in new capital plant per employee substantially below the average for the Nation's sawmills: Pennsylvania invested 45.1 percent less; Kentucky, 55.5 percent less; and West Virginia, 65.2 percent less, indicating a much greater reliance on capital by the Nation's predominantly softwood sawmill industry and the relative undercapitalization in the hardwood lumber industries. Further, the lack of adequate capital is thought to be especially prevalent in the "middle-size" hardwood mills.

Pennsylvania, with the largest sawmill industry, led in total expenditures for new and used capital plant and equipment with a $7,500,000 investment in 1982—over twice that of Kentucky ($3.69 million) and West Virginia ($3.03 million). Total expenditures per lumber mill in Pennsylvania averaged $20,000, which was about equal to the average investment per plant for "All Manufacturing" in the state. And although Kentucky's and West Virginia's lumber mills were larger than Pennsylvania's in terms of physical output, they made less investment per mill ($18,897 in Kentucky and $16,724 in West Virginia), both significantly below that of Pennsylvania mills, and substantially below each respective state's average for "All Manufacturing" plants.

However, investment in new capital plant and equipment is a more relevant indicator of technical innovation in the tristate lumber industry. In two of the states, new capital investment per employee averaged more than that for each state's total lumber and wood products industry: 28.8 percent greater in Pennsylvania and 7.1 percent more in Kentucky. West Virginia's sawmills had the lowest new capital expenditure per employee, at $1,095; this figure was 22.1 percent less than the average expenditure by the State's

Table 9.—Capital expenditures in tristate lumber and lumber and wood products sectors, and All Manufacturing, by area, 1982

Area and sector	Investments in: New capital per employee	Used capital per employee[a]	Capital expenditures by employee	Total
		-Dollars-		
Pennsylvania				
Lumber[b]	1,727	545	2,273	7,500,000
Lumber/wood products[c]	1,341	152	1,493	25,380,000
All manufacturing	2,873	203	3,076	3,630,500,000
Kentucky				
Lumber[b]	1,400	445	1,845	3,690,000
Lumber/wood products[c]	1,307	148	1,456	10,910,000
All manufacturing	4,042	858	4,900	1,208,500,000
West Virginia				
Lumber[b]	1,095	348	1,443	3,030,000
Lumber/wood products[c]	1,405	160	1,564	6,570,000
All manufacturing	4,110	276	4,386	420,100,000
United States				
Lumber[b]	3,145	995	4,139	546,000,000
Lumber/wood products[c]	2,498	282	2,780	1,602,400,000

Note: Data may not total due to rounding.

[a] Estimated for lumber industry in three states based on U.S. lumber industry (SIC 2421) average.

[b] SIC 2421.

[c] SIC 24.

Source: U.S. Department of Commerce, Bureau of the Census 1985a,b, 1986.

total lumber and wood products sector. This occurred despite the sawmill industry's prominence in the state lumber and wood products sector, accounting for 39 percent of that sector's total capital investment in 1982.

Material Costs

Materials constitute a major part of the total cost of producing grade hardwood lumber. Material costs represent, in this context, all physical items put into production during the year by the firm and industry. Based on the Census of Manufactures definition, the "materials costs" classification broadly includes: raw materials, parts, containers, production and operating supplies, energy, production contract work, and products bought and resold in the same condition.

In 1982, material costs for lumber production in Pennsylvania, Kentucky, and West Virginia totaled $234 million (Table 10), or about 3.5 percent of that for the U.S. lumber industry. This represented about 23.6 percent of the total cost of materials used by the tristate's entire lumber and wood products sector, but only about 0.29 percent of the area's total material inputs for "All Manufacturing." However, it should be of interest to suppliers and developers to note that in Pennsylvania, for example, annual materials costs alone (locally purchased timber and supplies) in the sawmill industry averaged $317,067 per establishment and $36,030 per person employed. From an economic development perspective, this compared quite favorably with a materials cost expenditure of $37,647 per employee by Pennsylvania's total lumber and wood products sector and with the average expenditure of $47,896 per employee by the State's "All Manufacturing" sector.

Among the states, Pennsylvania's sawmill industry was the leading user of materials, totaling $118.9 million in 1982. This was 3 percent more than the total of the combined industries of Kentucky and West Virginia, and represented

Table 10.—Material costs in tristate lumber and lumber and wood products sectors, by area, and U.S. lumber sector, 1982

Area and sector	Material costs by:		
	Total	Plant	Employee
	----------Dollars----------		
Pennsylvania			
Lumber	118,900,000	317,100	36,030
Lumber/wood products	640,000,000	530,000	37,647
West Virginia			
Lumber	56,900,000	314,400	27,095
Lumber/wood products	122,600,000	326,600	29,190
Kentucky			
Lumber	58,200,000	298,500	29,100
Lumber/wood products	228,200,000	457,300	30,427
United States			
Lumber	6,674,200,000	1,056,700	50,600

Source: U.S. Department of Commerce, Bureau of the Census 1984a,b,c,d, 1985a,b.

18.6 percent of the toal materials purchased by Pennsylvania's solid wood industry. Expenditures for materials averaged $317,067 per mill, which was slightly greater than that for West Virginia (0.9 percent) and moderately higher than that for Kentucky (6.2 percent). Since the sawmills in both Kentucky and West Virginia had a larger average volume of lumber output, Pennsylvania's higher material input costs are thought to reflect a higher degree of competition for available raw materials, and perhaps a larger proportion of high-quality timber—either in terms of species or grade, or both.

The total material cost for Kentucky sawmills was $58.2 million and represented about 25.5 percent of the $228.2 million used by the State's entire lumber and wood products industry. West Virginia's material costs were the lowest among the three states, but it had the lowest volume of output. However, its materials cost of $56.9 million represented about 46.4 percent of the total used by the State's lumber and wood products sector, making it by far the dominant purchasing segment of West Virginia's solid wood sector. West Virginia's expenditures per employee for materials also were the least among the three states—$27,095 per employee versus $29,100 for Kentucky and $36,030 for Pennsylvania. Relative to Kentucky, this was due primarily to a lower volume processed per employee, and to Pennsylvania, due to a combination of smaller volume processed and lower price per unit.

Summary of Factor Inputs

The total cost of producing grade lumber in Kentucky, Pennsylvania, and West Virginia in 1982 was about $350,100,000 (Table 11). Materials and labor were the major inputs into the production process—accounting for 94.6 percent (66.8 and 27.8 percent) of the total cost of production. The balance of the costs included expenditures for new and used capital plant and equipment (4.1 percent) and purchased services (1.3 percent).

Materials—including contract timber logging, energy, resales, and supplies—was the predominant cost in producing lumber. Material costs ranged from 67.7 percent of total production cost in Pennsylvania—which was significantly influenced by higher prices paid per unit of higher value raw material—to 65.2 percent in West Virginia, which was affected by the lowest prices paid for high value raw material. The lumber industries in all three states had a lower proportion of total costs in materials than the U.S. lumber industry, though this was not a situation favorable to relative efficiency in the tristate hardwood industry. Rather, it was a result of: (1) the lower physical output per unit of labor (and higher unit cost of labor) in the hardwood industries compared with the predominantly softwood U.S. lumber industry; and (2) the proportionately larger volumes of materials purchased and processed by the U.S. industry due to its higher physical productivity.

As suggested, labor—as a proportion of total costs—was higher in the tristate lumber industry than in the United States by about 10 percent. West Virginia's industry—which had the lowest material cost—averaged the highest cost of labor input at 30.0 percent of total production cost. This was due mostly to the lower physical output per man-hour and significantly higher supplemental labor costs in West Virginia's lumber industry. Of the three states, Pennsylvania's labor input accounted for the smallest proportion of the total cost of lumber production.

Capital expenditures, the third major cost item in the production process, ranged from 4.3 percent of total cost in Pennsylvania to 3.4 percent in West Virginia. In all three hardwood lumber-producing states, however, capital expenditures were a less significant item of total cost than was evidenced in the U.S. lumber industry (23.2 to 39.3 percent lower). This may further reflect undercapitalization in the tristate hardwood lumber industry.

Summary and Conclusions

In an economy where increasing efficiency is stressed, improvements in productivity and performance among all economic factors of production—such as land, labor, capital, management, and entrepreneurship—are necessary for an industry to remain competitive in the marketplace. In the following tabulations and tables are measures that are useful in the management of operations to evaluate performance. Used collectively and in conjunction with the earlier displays and discussions, they provide insight into the operational status and productive differences among the tristate hardwood lumber industry. Combined with forthcoming performance trends analyses and current, site-specific data, these measures provide the foundation for improved efficiency, development, and policy initiatives by the firm, industry, and concerned institutions.

Measures of Productivity and Performance

Productivity measures are standardized concepts that carry a common understanding. They measure the relationship between quantity of resources used and quantity (or value in constant terms) of outputs. They are not precise measures of individual factor efficiency, but are highly accepted and applied indicators of the efficiency with which a resource is used. For example, the ratio of output per employee hour (labor or capital productivity) does not measure a specific contribution, such as labor or capital. Rather, it reflects the joint effect of these factors and others such as changes in technology, capacity utilization, plant design and layout, skill and effort of the work force, managerial ability, and labor-management relations.

The following tabulation provides 1982 measures of productivity for the tristate and U.S. lumber industries (SIC 2421). In the tabulation, ratios involving hours represent all employee plant hours worked; also, capital productivity equals value added minus payroll (VAMP) divided by all employee plant hours worked (Schallau et al. 1985).

Area	Labor productivity bf/hour	Unit Labor cost/payroll Dollars/bf	Capital productivity Dollars/hr	Value added as percent of shipments	Value added per hour Dollars
Kentucky	77.4	.0730	4.21	36.5	10.15
West Virginia	66.5	.0821	4.98	41.5	10.44
Pennsylvania	66.2	.0913	4.30	33.7	10.35
U.S.	117.8	.0673	4.78	32.2	12.71

Table 11.—Input cost distribution of major operational factors in tristate and U.S. lumber industries by area (SIC 2421), 1982[a]

Area	Total costs	Material costs	Labor costs	Capital expenditures	Purchased services
	Million dollars			*Percent*	
Pennsylvania	175.5	67.7	26.7	4.3	1.3
Kentucky	87.4	66.6	27.9	4.2	1.3
West Virginia	87.2	65.2	30.0	3.4	1.3
United States	9,829.0	67.9	25.3	5.6	1.2

[a] Costs are necessarily conservative due to lack of cost information on undepreciated assets; labor includes estimated supplemental costs; purchased services are based on U.S. lumber industry (SIC 2421) average (data may not total due to rounding).
Source: U.S. Department of Commerce, Bureau of the Census 1985a,b.

Table 12.—Supplemental measures of performance in tristate and U.S. lumber industries, by area (SIC 2421), 1982

Ratio	West Virginia	Kentucky	Penn-sylvania	United States
Cost: input/output (percent)				
Materials/value of shipments	59.6	61.8	61.6	66.3
Materials and payroll/shipment value	86.0	87.7	85.8	91.0
Payroll/value added	52.3	57.3	58.4	62.4
Total labor cost/value added[a]	66.2	70.8	72.0	76.9
New capital plant/value added	5.8	8.1	8.8	12.8
Payroll/man-hour worked (dollars)	5.46	5.65	6.05	7.83
Total labor cost/ man-hour worked[a] (dollars)	6.92	6.99	7.46	9.77

[a] Includes estimated supplemental labor costs.

Labor Productivity

The physical output per man-hour (labor productivity) in Kentucky's lumber industry was the highest among the three states, at least 10.6 percent higher than in West Virginia or Pennsylvania in 1982. Stated another way, Kentucky's sawmills required only 12.55 man-hours of labor to produce a thousand board feet of lumber. In West Virginia and Pennsylvania, it took 15.05 and 15.10 hours of labor, respectively, to manufacture the same volume of products. Also, high physical productivity combined with moderately low wages (Table 12) resulted in Kentucky's sawmills attaining the lowest payroll labor cost (7.3 cents) per board foot of lumber produced. West Virginia's sawmill industry had the second lowest unit labor cost (8.2 cents/board foot) and Pennsylvania's had the highest (9.1 cents/board foot). Still, the industries of all three states experienced lower physical productivity and higher unit labor costs than the Nation's predominately softwood lumber industry. Given the relative nature of the inputs, outputs, and breakdown processes between the hardwood and softwood industries, this general relationship is to be expected.

Economic Performance

Upon changing from a physical to an economic perspective, which introduces output quality, a substantially different insight into the hardwood sawmill industry's performance is gained by considering the total costs of inputs relative to the values received for products sold, especially the value added. Value added (value of shipments minus all material costs) in the manufacture of goods is a major indicator of overall economic performance for both the firm and industry.

In overall economic performance, the lumber industries in all three states achieved relatively high productivity rates compared to the U.S. lumber industry. However, West Virginia's lumber industry was substantially more productive than that of Kentucky or Pennsylvania. In West Virginia, the monetary value added by the lumber manufacturing process represented 41.5 percent of the total value of products sold in 1982. This was substantially higher (13.7 percent) than the value added earned (36.5 percent) by the lumber industry in Kentucky, and 23.1 percent higher than that received (33.7 percent) by Pennsylvania's sawmill industry. The West Virginia industry's higher productivity was primarily due to its lower ratio (59.6 percent) of nonwage costs to value of shipments; that is, compared to the prices received for final products, the industry paid relatively lower prices for its raw materials, energy, supplies, and other material inputs than the Kentucky, Pennsylvania, or U.S. sawmill industries (Table 13).

West Virginia's lumber industry also achieved (1) the lowest labor cost relative to value added; and (2) the highest rate of dollar value added per man-hour worked by all employees, or $10.44 per hour. Sawmills in Pennsylvania ranked second with $10.35 value added per hour worked, and Kentucky's industry ranked third at $10.15 per hour. Although West Virginia's industry remained the most productive among the three states in value added per man-hour worked, its position was compromised somewhat because the full effect of the industry's lower relative material costs was not realized due to: (1) its lower physical output per man-hour compared to Kentucky's sawmills; and (2) the industry's lower output prices received compared to Pennsylvania's industry. The industries in all three states produced at least 17.9 percent less value added per man-hour than the U.S. lumber industry. This was primarily due to the latter's substantially higher labor productivity, which partially reflects the softwood lumber sector's higher capital intensity and technological innovations.

Capital Productivity

The performance of capital expenditures on investments in machinery, equipment, and plant structures was greater in the lumber industry of West Virginia than that of Kentucky, Pennsylvania, or the United States. Capital productivity, measured in terms of dollar returns per man-hours worked, was $4.98 per hour in West Virginia—or at least 15.8 percent greater than the $4.30 return in Pennsylvania and the $4.21 return in Kentucky. Also, West Virginia's capital investments were more productive than those of the Nation's lumber industry.

Since sawmills in West Virginia reportedly invested less per employee in 1982 than the other industries compared, a situation that has been prevalent since at least 1972 (Jones and Zinn 1986), the higher productivity experienced by the industry represents a phenomenon that defies simple explanation given the data at hand. However, several possible explanations come to mind, the most plausible of which are: (1) It is possible that the West Virginia lumber industry's emphasis on production as contrasted with trans-

Table 13.—Inputs as a proportion of value of shipments by tristate and U.S. lumber industries, by area (SIC 2421), 1982[a]

Area	Total value of shipments	Material costs	Labor costs[b]	Capital expenditures[c]	Purchased services	Total inputs
	Million dollars			*Percent*		
Pennsylvania	193.1	61.6	24.2	3.9	1.2	90.9
Kentucky	94.2	61.8	25.9	3.9	1.2	92.8
West Virginia	95.5	59.6	27.4	3.1	1.2	91.3
Total	382.8	61.1	25.4	3.7	1.2	91.5
United States	10,065.2	66.3	24.7	5.4	1.2	97.7

[a] See qualifications in Table 11 (data may not add due to rounding).
[b] Includes supplemental labor costs.
[c] Includes used capital expenditures.

actional activities (as evidenced by the almost 10 to 1 ratio of production workers to nonproduction workers) is especially conducive to enhancing the overall productivity of the firm and industry; (2) Since the West Virginia lumber industry produces a more homogeneous product output than either Pennsylvania or Kentucky, the invested capital may be more concentrated and, thus, more productive due to specialization; (3) Unreported investments in used capital could be of such a magnitude as to maintain or increase productivity and offset expenditures that otherwise would have been required for new capital plant.

Contributing to this situation are the following: (1) It is possible that the sawmill industry's undepreciated capital assets are disproportionately greater in West Virginia than in Kentucky or Pennsylvania; that is, the industry has newer productive assets in operation. Since data on these assets are not available, the question cannot be resolved; (2) It is possible that the larger size sawmills in the State account for the predominance of the new capital expenditures and perhaps operating at peak efficiency, and/or the combined output and efficiency of these mills is of such proportion as to distort the productivity ratio. Conclusive answers cannot be developed without further study.

Performance Relative to Social Objectives

On the basis of the measures cited, in 1982 the West Virginia lumber industry was the most productive in terms of economic efficiency; that is, the industry generated the highest total economic output relative to inputs among the three states studied. But West Virginia's lumber industry was not as efficient as the U.S. lumber industry in 1982. The U.S. lumber industry was more productive, I believe, due to its higher multifactor productivity of labor and capital combined in the production process with its homogeneity of product output.

Assuming this hypothesis concerning the U.S. lumber industry is correct, it appears that, as a whole, the tristate lumber industry is undercapitalized to the point of being unable to optimize output efficiency. This is not to deny that there are many highly efficient medium- to large-size mills operating within all three states. Other factors detrimental to the overall performance of tristate operations were:

1. The industries operated well below their reported normal (and probably preferred) capacities.

2. The Kentucky and West Virginia lumber industries operated substantially less than a full work-year, which resulted in the underemployment of labor and capital.

3. Both wages and total earnings in the sawmill industries of all three states were lower in all occupations than those in each respective state's other lumber and wood products industries and "All Manufacturing" averages, thus lessening their competitiveness for the most productive labor.

4. Material costs (predominantly raw materials) in Pennsylvania were substantially higher, even when considering a probable higher quality of raw materials in terms of species and grade, than in West Virginia or Kentucky. Thus, the question is raised of the adequacy of the performance of the markets for raw materials (values received) in the latter two states.

The demand for hardwood lumber products has increased since 1982 and is expected to continue to increase substantially in the years ahead (Phelps 1984). Since the tristate area is blessed with extensive and valuable forest resources—the economic potential of which are not being fully realized—and large, high capacity sawmill industries, the prospect for socially desirable economic development is a highly viable option. This is especially true in West Virginia, where a secondary wood-using industry remains seriously underdeveloped, but where efforts are underway to correct the situation (Dempsey and Price 1984; Zinn and Jones 1986).

The prominence of the tristate lumber industry as an optimum performing and economically competitive supplier in the years ahead will depend on: (1) the policies and strategies developed to use the resource in a socially desirable manner; (2) improving the creativity and productivity of management, especially in fostering technological innovations, more effective marketing and other transactional activities (Dempsey 1973); (3) ". . .improving the utilization of all inputs into the production and use of hardwood lumber. . ." as Luppold (1982) reported in an econometric study of the hardwood lumber market; and (4) the character and resolve of the entrepreneural actions taken by the firm, industry, and supporting institutions.

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Sawmill effectiveness is crucial to the growth and development of wood industries among locales, states, regions, and countries. Productivity ratios, structural factors, and other indicators of economic performance were used to measure the relative productive efficiency of the grade hardwood lumber industries in Kentucky, Pennsylvania, and West Virginia. Despite undercapitalization, the industries' latent capacity and efficiency potential provide the base and make the prospect for socially desirable economic development a highly viable option in all three states.

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NE-RP-605

Estimating Northern Red Oak Site-Index Class from Total Height and Diameter of Dominant and Codominant Trees in Central Appalachian Hardwood Stands

Neil I. Lamson

Abstract

Northern red oak site-index (SI) class is estimated using height and diameter of dominant and codominant trees for five Appalachian hardwood species. Methods for predicting total height as a function of diameter are presented. Because the total height of 4- and 6-inch trees varies less than 5 feet for the three northern red oak SI classes, use trees that are at least 8 inches in d.b.h. when estimating site class.

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Introduction

Determining site quality is one of the first steps in managing forest land. Once site quality is known, growth of wood products can be estimated and various forest management practices evaluated. For eastern hardwoods, the generally accepted method for estimating site quality is site index (SI) based on the 50-year height growth of dominant and codominant trees (Carmean 1975; Schnur 1937). Yield tables for managed and unmanaged stands have been developed for most of the hardwood forest types (Gingrich 1971; Leak and Filip 1970). Northern red oak (*Quercus rubra* L.) is one of the most widely used eastern hardwood SI species because it occurs over much of the eastern hardwood region and is found over a relatively wide range of site quality within most forest types (Fowells 1965).

Site index based on height over age has been determined for several upland hardwood species. But difficulties arise in determining the age of trees. Hardwoods are difficult to bore and the pith often is missed because of unsymmetrical radial growth. Also, slow-growing trees are difficult to age without magnification.

To avoid the problem of determining age, Stout and Shumway (1982) and Reinhardt (1983) described methods of estimating SI using height and diameter of dominant and codominant trees. This paper reports height/diameter relationships for five central Appalachian species and explains how to use height and diameter of dominant and codominant trees to estimate northern red oak SI class.

Methods

Fifty-six even-aged stands 20 to 80 years old were selected for study. All stands were located in north-central West Virginia within 25 miles of Parsons. Stand size ranged from 5 to 15 acres. Site index was estimated using height/age relationships of northern red oaks present in each stand (Schnur 1937). Within each stand, 10 to 60 dominant or codominant northern red oak, red maple (*Acer rubrum* L.), sugar maple (*Acer saccharum* Marsh.), yellow-poplar (*Liriodendron tulipifera* L.), or black cherry (*Prunus serotina* Ehrh.) trees that showed no outward signs of suppression or damage from fire, insects, or disease were selected for study.

Total height and diameter at 4.5 feet (d.b.h.) were measured on 2,550 study trees. Height was measured using a telescopic measuring pole or Relaskop. Diameter ranged from 3.0 to 38.1 inches and total height ranged from 15 to 115 feet.

Data on tree height and diameter were grouped by 10-foot-stand northern red oak SI class: 60 for 56 to 65 feet, 70 for 66 to 75 feet, and 80 for 76 to 85 feet.

Following Stout and Shumway (1982), data for each species/site index group were fitted to the equation:

$$Ln(H) = Ln(4.5 + a(1 - EXP(-bD)))$$

where H = total height
D = diameter at breast height (4.5 feet)
a = coefficient for the asymptote
b = slope coefficient
Ln = napierian logarithm

Results and Discussion

Asymptote and slope coefficients are shown in Table 1. Standard errors for the asymptote coefficients ranged from 1.613 to 13.460; for slope coefficients, standard errors ranged from 0.003 to 0.018.

These equations were used to estimate total height of dominant and codominant trees by 2-inch diameter class for each 10-foot SI class and species (Table 2).

Using the measured height and diameter, Table 2 was then used to assign each of the original 2,550 trees an SI class. The proportion of trees classified correctly is shown in Table 3. For simplification, the diameter classes are combined into three groups. About two-thirds of the trees were classified correctly as the classification improved with increasing diameter.

It is common to determine height and age of trees to estimate site index. When standing trees are used, workers commonly use an increment borer to extract a core and then count annual rings to obtain the age. Difficulties arise when the core does not include the pith because the tree is too large or unsymetrical. Also, it is difficult to detect annual rings of species such as sugar maple, or to count annual rings of slow-growing trees. Such difficulties are eliminated when total height and diameter are used to estimate SI class.

The use of height/diameter curves to estimate SI probably is accurate only when only dominant or codominant trees are used and SI is estimated to the nearest 10-foot class. This method should not be used with trees of lower crown classes or used to estimate SI in smaller than 10-foot classes.

When using Table 2, SI should be estimated to the nearest 10-foot class because the data used to compute the regression were grouped by 10-foot SI class. For example, if a codominant red oak tree is 14 inches d.b.h. and 80 feet tall, the estimated northern red oak SI class would be 70 feet.

Table 1.—Number of trees measured, values of asymptote (a) and slope (b) coefficients, and associated standard errors

Species	Site-index class	No. of trees measured	a	SE	b	SE
Red oak	60	203	79.450	1.613	0.137	0.005
	70	394	93.331	1.678	0.109	0.005
	80	212	111.848	2.030	0.098	0.004
Yellow-poplar	70	189	129.736	6.378	0.070	0.004
	80	433	148.125	3.686	0.066	0.003
Black cherry	60	43	76.175	3.986	0.151	0.012
	70	293	109.481	2.756	0.089	0.003
	80	320	128.483	3.739	0.077	0.003
Sugar maple	70	73	98.498	4.533	0.010	0.008
	80	145	112.150	3.651	0.087	0.005
Red maple	60	160	75.454	3.134	0.140	0.009
	70	48	89.130	6.747	0.129	0.018
	80	37	140.296	13.460	0.065	0.008

Table 2.—Estimated total height of dominant and codominant trees by diameter class, species, and northern red oak SI class (coefficients are from Table 1)

D.b.h. class (inches)	Red oak			Yellow-poplar		Black cherry			Sugar maple		Red maple		
	SI 60	SI 70	SI 80	SI 70	SI 80	SI 60	SI 70	SI 80	SI 70	SI 80	SI 60	SI 70	SI 80
	Feet												
4	38	37	41	36	39	39	37	38	37	38	37	40	37
6	49	49	51	49	53	50	50	52	49	50	47	52	50
8	57	59	65	60	66	58	60	63	59	61	55	62	61
10	64	66	74	70	77	64	69	73	67	70	61	69	72
12	69	72	82	79	86	68	76	82	73	77	66	75	80
14	72	77	88	86	94	71	83	89	79	84	69	79	88
16	75	81	93	92	102	74	88	95	83	89	72	82	95
18	77	85	97	98	108	76	92	101	87	93	74	85	101
20	79	87	101	103	114	77	96	105	90	97	75	87	107
22	80	89	103	107	118	78	99	109	92	100	76	88	111
24	81	91	106	110	123	79	101	113	94	103	77	90	115
26	82	92	108	113	126	79	103	115	96	105	78	90	119
28	83	93	109	116	130	80	105	118	97	107	78	91	122
30	83	94	110	119	133	80	106	120	98	109	79	92	125

Table 3.—Proportion of correctly classified trees of five Appalachian hardwood species (values are from Table 2)

Species	D.b.h. group[a]	No. of observations	% of trees classified correctly
Red oak	1	275	55
	2	231	53
	3	303	58
Yellow-poplar	1	267	64
	2	189	67
	3	166	68
Black cherry	1	381	44
	2	191	54
	3	84	73
Sugar maple	1	101	50
	2	52	65
	3	65	68
Red maple	1	164	53
	2	68	49
	3	13	62

[a] 1 = 4 to 8 inches; 2 = 10 to 16 inches; 3 = 18 + inches.

The height/d.b.h. formulae shown in Table 1 will be useful in estimating volume as a function of diameter and total height (Martin 1981). This should aid in the development of growth and yield models for mixed Appalachian hardwood stands where tree species and d.b.h. are observed and total height is estimated.

There is little variation in the estimated height of small trees. For example, the total height of trees 4 inches d.b.h. ranges from 36 to 41 feet for the five species across the three site classes (Table 2). Similarly, total height for 6-inch trees ranges from 47 to 53 feet. Therefore, to estimate site class using these data, use trees at least 8 inches d.b.h. The larger the trees, the more accurate will be the estimated site class.

Dominant and codominant red oak, black cherry, and red maple trees will be about 9 inches d.b.h. at stand age 50 on SI class 60 areas (Table 2). Dominants and codominants at stand age 50 average about 10 inches d.b.h. on SI class 70 areas and about 11 inches d.b.h. on SI class 80 areas. These are reasonable values for stands in the central Appalachian hardwood region.

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Northern red oak site-index (SI) class is estimated using height and diameter of dominant and codominant trees for five Appalachian hardwood species. Methods for predicting total height as a function of diameter are presented. Because total height of 4- and 6-inch trees varies less than 5 feet for the three northern red oak SI classes, use trees that are at least 8 inches in d.b.h. when estimating site class.

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User's Guide for the Northern Hardwood Stand Models: SIMSAP and SIMTIM

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Abstract

SIMSAP and SIMTIM are computer programs that have been developed to simulate the stand growth and development of natural and treated even-aged northern hardwood stands. SIMSAP begins with species distributions by quality classes in sapling stands after regeneration. SIMTIM, the poletimber-sawtimber-harvest phase, uses stocking guides based on quadratic mean stand diameter, number of trees, and basal area per acre of trees in the main crown canopy. Using available data, the connecting phases of the models have been tested to determine the effects of silvicultural treatments (or no treatment) on long-term stand response. The models are coded in FORTRAN 77 and are available on mainframe and IBM compatible microcomputers with a minimum of 256 K.

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Introduction

SIMSAP and SIMTIM form a forest stand growth model for even-aged northern hardwood stands (Solomon 1977a, Solomon and Leak 1986). The models can be applied to northern hardwood stands across New England to simulate growth beginning with a sapling stand (SIMSAP), continuing to a poletimber-sawtimber stand, and terminating at a user-specified quadratic mean stand diameter or stand age (SIMTIM).

The major species from the northern hardwood stands across New England used to construct the models were:

Yellow birch	*Betula alleghaniensis* Britton
Sugar maple	*Acer saccharum* Marsh.
White ash	*Fraxinus americana* L.
Paper birch	*Betula papyrifera* Marsh.
Red maple	*Acer rubrum* L.
Beech	*Fagus grandifolia* Ehrh.
Aspen	*Populus tremuloides* Michx.
Hemlock	*Tsuga canadensis* (L.) Carr.
Red spruce	*Picea rubens* Sarg.

The programs that were used to construct the models have been modified to allow interactive input data to be stored for later use. The user is prompted for information after which the data are checked for reasonable values. Both models are written in FORTRAN 77 and have on-line instructions available. SIMSAP/SIMTIM utilize MS-DOS on IBM PC-compatible microcomputers[1] with at least 256 K or on any mainframe (Solomon 1986).

SIMSAP Components

The development of the sapling stand has been described as a compound exponential process (Leak 1969a) that provides a basis for determining changes in numbers of stems by species group during the sapling stage. Available data on potential quality classes are used. After a weeding treatment is applied, the shape of the exponential curve will change, thus changing the rate of mortality. Also, a pruning treatment will change the quality distribution of the stems in the residual stand.

The initial stand information needed is the site index and species composition. The site index is defined as height of sugar maple at base age 50, and species composition is expressed as a percentage of the basal area in the initial stand at 1 inch d.b.h.

The silvicultural treatments available are weeding and pruning operations. The pruning option, if specified, will prune all yellow birch and sugar maple crop trees less than veneer grade to one log length. If weeding is desired, the user must supply a beginning average stand diameter; upper and lower bounds of number of acceptable stems, within which limits weeding will not be canceled; number of crop trees to be released; average number of competitors to remove per crop tree; and the removal priorities of beech, yellow birch, sugar maple, red maple, paper birch, and white ash.

The sapling-stand phase of the model is a series of subroutines that can be categorized as: (1) determination of initial stem numbers and qualities, (2) computation of mortality patterns, (3) application of an optional weeding treatment, and (4) determination of diameter distribution and elimination of understory trees.

Stem Numbers and Quality

SIMSAP begins the sapling-stand phase by determining the number of stems in the stand at a quadratic mean stand diameter (QMD) of 1.0 inch, and proportions the stems by species with veneer-, sawlog-, and bulk-product potential. The subroutine SAPST draws an initial observation at random from a normal distribution that represents a stand with a 1.0-inch mean stand diameter and 4,922 trees per acre, with a standard deviation of 779 trees[2] (Leak 1969b, Marquis 1967). The species composition remains constant for this phase of the simulator. The range of percentage of trees in potential stem qualities by species has been estimated (Solomon 1974) (Table 1). The subroutine picks uniformly distributed random numbers within the indicated ranges and sets these equal to the proportions of veneer-, sawlog-, and bulk-quality stems.

Table 1. — Ranges in the percentage of number of trees, by species, in various potential product classes

Species	Veneer	Sawlog	Bulk
Beech	5	8	87
Yellow birch	4-10	11-19	71-85
Sugar maple	3-5	12-27	68-85
Red maple	14	18	68
Paper birch	7-38	25-28	34-68
White ash	30	16	54

[1] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

[2] Leak, William B. 1967. Final report. Estimation of the exponential rate of tree dropout in young even-aged northern hardwoods. Durham, NH: USDA Forest Service, Northeastern Forest Experiment Station. 10 p.

Mortality

The number of stems (x) in a sapling northern hardwood stand decreases as stand diameter increases according to a negative exponential probability distribution (Leak 1969a, b) that has the form:

$$f(x) = re^{-rx}$$

The negative exponential parameter "r," for commercial stems alone and for all species together, is estimated by subroutine RPAR. Subroutine DROP applies mortality losses from an initial diameter of 1.0 inch to either the diameter at which weeding is applied or to the 3.0-inch mean diameter that marks the end of the sapling stage.

The average value of "r" for all species together is a constant 0.5685. For the commercial number of stems (CN) (average of 3,466 per acre), "r" can be estimated by (Solomon 1977a):

$$r = \begin{cases} 0.4428 + 0.0255\ (CN - 3466)/1768 \text{ for } CN > 3466. \\ 0.4428 - 0.0682\ (3466 - CN)/1768 \text{ for } CN < 3466. \end{cases}$$

If we have the initial number (N_1), initial diameter (D_1), and the final diameter (D_2), the final number of stems of all species (N_2) can be calculated in subroutine DROP from:

$$N_2 = N_1 \exp[r(D_1 - D_2)].$$

Multiplying the number (N_2) by the species and quality-class proportions gives the number of trees per species and class.

Silvicultural Treatments

A user may apply the subroutine CLEAN at any specified mean stand diameter between 1.0 and 3.0 inches by specifying a high and low number of acceptable stems. Acceptable stems depend on the management and product objectives implemented by the forest manager. The management decision must be made for top-grade products such as millwood, sawlogs, or veneer logs. The product decisions would be based on a sufficient number of the desired tolerant, intermediate, or intolerant species to accomplish the management objective. A stand should have more than the minimum number of acceptable stems so that after silvicultural treatments the residual stand will be composed of the desired species to accomplish the management objectives. A stand with less than the minimum number of acceptable stems should be considered for regeneration. Beyond a maximum number of acceptable stems, sufficient quantities of the desired species exist and a weeding treatment is not required to accomplish the management objectives. The user may also specify the number of crop trees, species priorities, and number of competitors to be removed per crop tree. Crop trees are stems with grade 1 or 2 potential, and the number of trees to remove is computed by multiplying the number of crop trees times the number of trees to be removed around each crop tree. Also, pruning may be applied to the first log of all yellow birches and sugar maples with grade 2 potential, thereby increasing their potential to grade 1.

The number of trees at the end of the sapling stage is estimated by using the exponential parameter "r" calculated by comparing the number of stems remaining after weeding with the average number in an undisturbed stand. According to the stocking guide, no mortality is expected if the number of stems is 400 or less (5-inch mean stand diameter). Therefore, the exponential to apply after weeding to project the final number of trees would be:

$$r = 0.4428\ (\text{residual remaining} - 400.0)/(XN - 400.0)$$

with

$$\log_{10} XN = 4.016316 - 0.2273\ (\text{mean diameter})$$

where XN is the average number of trees in an untouched stand for a given stand diameter.

In projecting numbers of trees, no mortality losses are applied to crop trees. The negative exponential losses are applied only to those residual stems not classed as crop trees. Thus, the final result from subroutine CLEAN is numbers of stems by species and quality classes at a mean stand d.b.h. of 3.0 inches.

Diameter Distribution

In managing even-aged northern hardwoods beyond the sapling stage, silvicultural work is applied primarily to trees that make up the main crown canopy. Thus, the subroutine DIAMD assigns trees to diameter classes and eliminates the understory trees. This step results in a loss in number of stems, an increase in average stand diameter, and changes in species composition.

On the basis of plot data from young northern hardwood stands about 3.0 inches mean stand diameter (Leak 1969a), the observed ranges in percentage of trees by diameter class have been grouped in Table 2. Subroutine DIAMD chooses a random observation within each range, and determines numbers of trees by diameter class and species. Then, the 1-, 2-, or 3-inch (cumulative) class is dropped to reduce the stand to 760 trees per acre or less. This procedure brings the stand into the lower end of the northern hardwood stocking guide (Fig. 1) at an average diameter of approximately 5 inches. Beech or sugar maple designated as crop trees, and released by weeding, are not eliminated as understory.

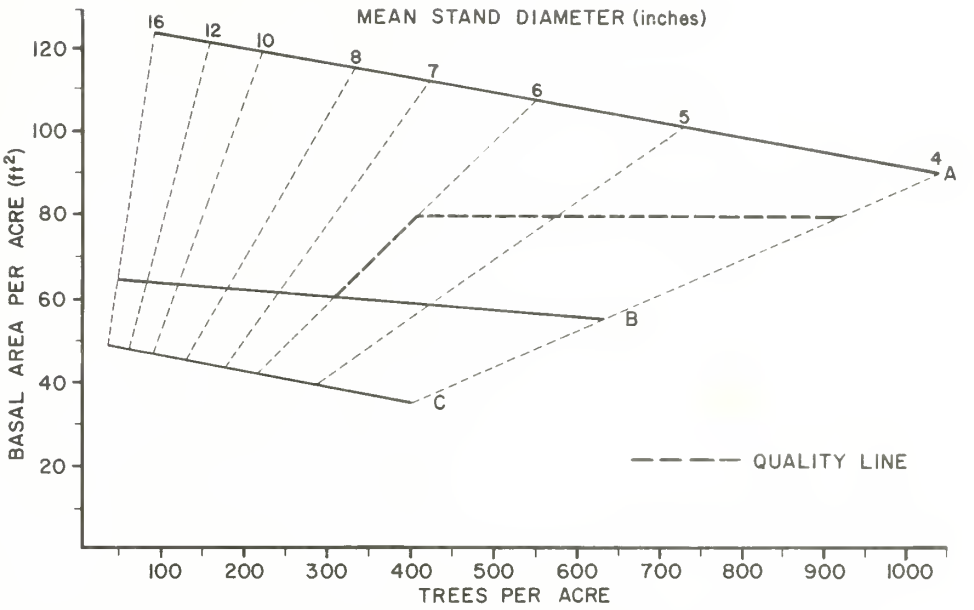

Figure 1.—Stocking chart for northern hardwoods is based on trees in the main crown canopy. The A line is average maximum stocking. The B line is recommended minimum stocking for adequate growth response per acre. The C line defines the minimum amount of acceptable growing stock for a manageable stand. The quality line defines the stocking measure in young stands for maintaining quality stem development.

Finally, the subroutine determines numbers of remaining trees by species and product class, as well as the final average diameter and basal area per acre. This information can serve as part of the input into the poletimber-sawtimber-harvest phase of the simulator.

Table 2. — Range in percentage of number of trees in each diameter class for stands with 2.5- to 3.0-inch average diameter, by species

Diameter class (inches)	Beech and sugar maple	Yellow birch, red maple, and white ash	Paper birch and others
1	34-71	0-54	0-20
2	20-34	0-34	0-30
3	6-14	3-27	0-25
4	1-10	10-37	0-25
5	0-8	0-34	12-50
6	0-3	0-25	0-50
7	remainder[a]	0-20	0-50
8	—	0-20 remainder	0-14 remainder

[a] Remainder is the remaining percentage if the diameter classes do not add to 100 percent.

Sapling MAIN Program

The MAIN program estimates number of years required to reach the end of the sapling stage. These time estimates are based on site index and the application or nonapplication of weeding; computations are made by simple interpolation between the following site index values (Leak et al. 1969):

Site Index	Weeded (Years)	Unweeded (Years)
50	44	59
60	38	50
70	33	44
80	29	40

SIMSAP Application

SIMSAP will prompt the user with a menu that can be used to determine the scope of each run. All of the input data will be stored on disk in a direct access file. The user is asked to provide the name of this file and whether it is an existing file or a new file. On subsequent runs the user can use this file to either duplicate an earlier run or make modifications to run the simulation under different conditions. The output for the run can be directed to either a disk file, a printer, or to the console.

The user selects an option from the following menu:

(1) HELP	(6) WEEDING
(2) NEW FILE	(7) PRUNING
(3) TITLE	(8) RANDOM #
(4) INITIAL STAND	(9) # REPEAT RUNS
(5) SITE INDEX	(10) DISPLAY FILE

<11> EXECUTE

All items enclosed in <> (option 11) are default values and will be in effect if a carriage return is entered. Entering a minus sign in response to any question will terminate the program.

Option (1):

Help — A summary of instructions for creating the input data file is printed on the console. After every 15 to 20 lines, the program waits for a carriage return before continuing.

Option (2):

New File — A new input file is to be created from the information contained in options 3 thru 9. If a file of this name already exists, the user will be given the choice of renaming the file, returning to the menu, or continuing, which will cause the existing file to be erased.

When the user has specified a new input data file, only options 1 and 2 are available. After the file is created or if the file has been designated as an existing file, options 3 thru 9 will allow modifications to that file without having to re-create the whole file.

Option (3):

Title — A title of up to 80 characters will appear at the top of each page of output.

Option (4):

Initial Stand — The user enters the percentage of the basal area of each species in the stand at 1-inch quadratic mean stand diameter. The species groups are: beech (BE), yellow birch (YB), sugar maple (SM), red maple (RM), paper birch (PB), white ash (WA), pin cherry (PC), striped maple (STMAP), aspen (ASP), other (OTH), and red maple sprouts (RMSP). If the percentages do not add to 100, the user is asked to reenter the percentages.

Option (5):

Site Index — The site index for the stand is based on sugar maple at base age 50 and must range between 40 and 80.

Option (6):

Weeding

DBH — The quadratic mean stand diameter at which to start weeding must be between 1.0 and 3.0 inches.

Max # acceptable stems — No weeding will be applied if the number of acceptable stems is greater than this number when the stand reaches the weeding d.b.h.

Min # acceptable stems — No weeding will occur if the number of acceptable stems is less than this number when the stand reaches the weeding d.b.h.

crop trees — The number of crop trees per acre to be released.

competitors — The average number of competitors removed per crop tree to ensure survival of the crop tree.

Priority — Removal priority for each species: beech, yellow birch, sugar maple, red maple, paper birch, and white ash. Priorities range from 1 (first) to 6 (last) and numbers may **not** be repeated. A zero may be used for species without crop trees.

Option (7):

Pruning	(1) The released yellow birch and sugar maple trees less than veneer quality are pruned to one log during weeding to increase quality. (2) No pruning will be done.

Option (8):

Random #	The random number generator in the model requires an odd, nine-digit number to begin.

Option (9):

# Repeat Runs	Because of the randomness within the model, the stand can be run through several simulations and each will be slightly different. The user can use these results to obtain an average stand value.

Option (10):

Display File	A summary of the input data will be displayed on the console.

Option <11>:

Execute	The input data are then used to start the simulation.

An example of creating the input data file and the subsequent simulation is shown in Table 3. The entries in italics are made by the user. All input is free format, that is, data need only be separated by one or more blanks or a comma. There is no need to align the entry under a column heading other than for the user's own convenience. At the completion of the model run, the user is asked if another simulation is desired with this stand. If the answer is yes (Y), the program returns to the menu. If the answer is no <N>, the user is asked if a simulation with a new input data file is desired. A Y response will return the user to entering a file name for the input file and a designation for the output. An N response will terminate the program.

SIMSAP Output

The output of SIMSAP (Table 3) starts with a copy of the input data. The model indicates the number of yellow birch and sugar maple trees to be pruned. An appropriate message is printed when weeding was not conducted or when the number of acceptable stems was not within the allowable range. After a weeding, the diameter at which it occurred is given, along with the number of crop trees by species, number of trees cut, and the number of remaining trees.

At the end of the sapling phase, the smaller diameter classes that were dropped from the understory are noted and the final stand characteristics: number of trees, basal area per acre, QMD, and number of years to reach the end of the sapling phase are presented. For commercial species, the number of trees and percentage of composition are given by three quality classes which may be considered as veneer, sawlog, and bulk product. The number of trees and percentage of composition of the noncommercial species are printed without quality classes.

SIMTIM Components

The poletimber-sawtimber-harvest phase of the simulator (SIMTIM) grows the stand from the end of the sapling phase, approximately 4.5 inches QMD, to harvest diameter or rotation age. The program covers three main steps: (1) stand growth projection, (2) thinning and harvesting options, and (3) paper birch-aspen mortality.

The overall framework of the model is a distance-independent stand model. Input consists of site index, specifications on the thinning regime, and stand characteristics of age, basal area, QMD, and percentage of basal area by species and quality. The model projects these stand characteristics by positioning the stand within the northern hardwood stocking chart (Fig. 1) and relating stand development to stocking (Solomon and Leak 1986). The lines in Figure 1 are developed from trees within the main crown canopy of northern hardwood stands. The main crown canopy is defined as all trees on the plot that are not overtopped or suppressed.

The user is required to input the following information:

- Forest stand name;
- Site index between 40 and 80 for sugar maple at base age 50;
- Average number of trees per acre, usually between 25 and 1,500 trees;
- Basal area per acre to the nearest tenth of a square foot between 20 and 130 square feet;
- Quadratic mean stand diameter to the nearest tenth of an inch between 4 and 16 inches;
- Species composition list;
- Stand age in years;
- Final harvest age in years, and final quadratic mean diameter to the nearest tenth of an inch;
- Specified intervals in years for report to be presented;
- Any odd nine-digit number for the mortality function.

The species composition list is entered by quality classes of I, II, and III, in the following order: beech, yellow birch, sugar maple, red maple, paper birch, aspen, white ash, conifer, and other. There is one quality class of eight values per line expressed to the nearest tenth of a percent (Table 4).

Stand Growth

Stand growth provides the forest manager with an estimate of the growth of northern hardwood stands. The growth rate of different species may increase or decrease depending upon the age and density of the stand. Thus, stand growth, as computed from accretion, ingrowth, and mortality, is proportioned into species growth rate based on the residual basal area of the stand and stand age. Changing species composition does not change stand growth, but changes the amount of growth allotted to individual species which then reproportions the species composition.

The changes in growth rates for stands growing on different sites are modeled as a proportion of the site index of the stand to site index 60 for northern hardwoods. The stand basal area is adjusted by that ratio since the stand growth within the model is based upon northern hardwood stands growing on a site index 60 for sugar maple base age 50.

The amount of stocking, represented by the basal area, number of trees, and quadratic mean stand diameter, can be followed through time with the stocking chart (Fig. 1). The growth simulation within the model computes the number of trees per acre at both the A and B line. The A line represents a fully stocked stand without any form of management. The B line is based on optimum stand growth from different studies of northern hardwood growth. The number of trees at both the A and B line can be represented as a function of the natural logarithmic value of the quadratic mean stand diameter:

$$\text{A line number of trees} = e^{(9.491 - 1.786 * \ln QMD)}$$
$$\text{B line number of trees} = e^{(9.082 - 1.887 * \ln QMD)}$$

where

QMD = the diameter at breast height of the tree of average basal area.

The C line represents a managed stand with a minimum level of acceptable growing stock (sawlog potential) that will grow to the B line in 10 years. The quality line maintains a higher level of basal area stocking for smaller quadratic mean diameters. Thinning a stand to the quality line when less than 6 inches in diameter provides clear bole form on younger, smaller high-quality species (Leak et al. 1987).

The stand growth components of accretion and ingrowth (ft^2/acre/year) can be expressed as:

$$\text{Accretion} = 2.153 + 0.005\ (\ln BA) - 0.0076\ (SAW)$$
$$\text{Ingrowth} = 3.200 - 0.643\ (\ln BA) - 0.0012\ (SAW)$$

where

BA = residual basal area in square feet,
SAW = percentage of stand in sawtimber-size trees,
Accretion = d.b.h. increment in basal area of trees present at the initial inventory, plus ingrowth accretion,
Ingrowth = trees that grew larger than threshold size (5.0 inches) between inventories.

The R^2 values were 0.73 and 0.97; the standard errors of the mean were 0.0187 and 0.0138, respectively. These growth equations are based on information from managed stands of northern hardwoods (Marquis 1969; Solomon 1977b, c). The residual basal areas ranged from 20 to 100 square feet per acre for these stands that were 20 to 80 years old. The percentage of sawtimber ranged from zero to 60. Stand mortality increases as the basal area and mean stand diameter increase and the stand grows from the B to the A line. The estimate of actual stand mortality is based on the assumption that mortality at minimum stocking (B line) is zero, and that mortality of a stand above the B line is in some way proportional to its position between the A and B line.

$$\text{Stand mortality} = \left[\frac{BA - BAB}{BAA + MF - BAB}\right]^X (GG - BAGA)$$

where

BA = basal area of stand,
BAB = basal area at B line for the present QMD,
BAA = basal area at A line for the present QMD,
GG = gross growth,
BAGA = annual net basal area growth at A line for the present QMD,
MF = mortality factor,
X = a random exponent between 1 and 1.5.

When X = 1, mortality is computed in direct proportion to the position of the stand between the A and B line. When X is greater than 1, the mortality rate increases as the A line is approached and passed. The mortality factor (MF) ranged from -2.5 for stands with basal area of 60 square feet per acre or less up to 2.0 for stands with 100 square feet per acre or more.

Thinning and Harvesting Options

The user can specify the order of removing the eight species categories from the three quality classes. The numbers from 1 to 24 in the 3 x 8 matrix can be arranged to indicate removal priority. A number can be given that specifies the

location in the removal order for the user to switch from complete species-quality class removal to proportional removal of remaining species quality classes. This can be used to maintain species composition as well as quality within species.

Thinning is regulated by basal area in the stocking chart (Fig. 2). The user options include no thinning, thin when the stand reaches the A line, or when the stand reaches a user-specified basal area above the B line. The user must specify the quadratic mean diameter to the nearest tenth of an inch for the first thinning to begin. The thinning is to the B line except when it may be regulated by the quality line up to a 6-inch quadratic mean stand diameter. When thinning is controlled by the quality line, the stand is thinned to 80 square feet for stands with quadratic mean diameters less than or equal to 6 inches, and then is thinned to the B line for stands with quadratic mean diameters greater than 6 inches. The final harvest, specified by the user, may be based on time (number of years) or occur at the predetermined quadratic mean stand diameter.

Paper Birch — Aspen Mortality

When the stand reaches 80 years of age, simulated mortality of any remaining paper birch and aspen is accelerated by subroutine PBMORT to represent the short life span of these two species. Five percent of the initial amount of each species is removed per year, resulting in complete removal of both species between 80 and 100 years of age (Solomon and Leak 1969). Mortality losses are applied proportionally across all quality classes. The user has the opportunity to circumvent this accelerated mortality by specifying that paper birch and aspen be removed first in thinnings after age 70. Percentages of the remaining species are adjusted so that they continue to sum to 100 percent.

SIMTIM Application

SIMTIM is designed similar to SIMSAP in that it too uses a direct access file to store the input data and uses a menu to create or modify this input file. The user must provide a name for the input file, and specify whether it is a new or an already existing file. The user must specify where output is to go: the console, the printer, or a disk file. The menu for SIMTIM is presented to the user:

(1) HELP	(6) INITIAL COMPOSITION
(2) NEW FILE	(7) THINNING
(3) TITLE	(8) ROTATION
(4) SITE INDEX	(9) RANDOM #
(5) INITIAL STAND	(10) DISPLAY FILE

<11> EXECUTE

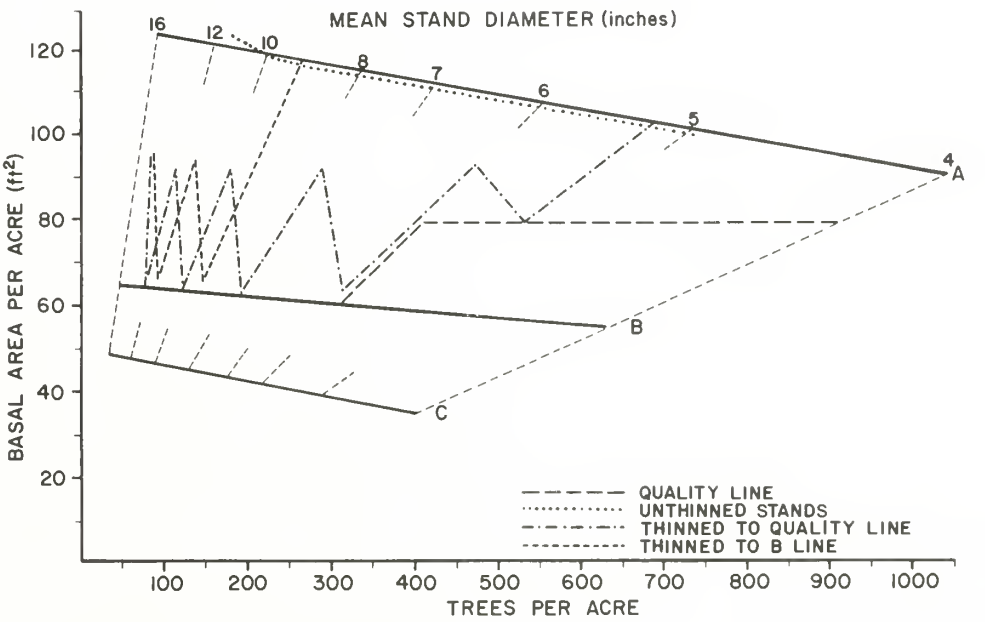

Figure 2.—Comparison of growth response for unthinned stands, stands thinned to the quality line starting at 5.0 inches quadratic mean stand diameter, and thinned to the B line starting at 9.0 inches quadratic mean stand diameter.

Option (1):

Help — A summary of instructions will be printed on the console. The program will wait after every 15 to 20 lines for a carriage return to be entered before continuing.

Option (2):

New file — If a file of the above specified name already exists, the user will be given the choice of renaming and creating a new file, returning to the menu, or continuing, which will cause the existing file to be erased. When the input data file has been designated as being new, the user can only select options 1 or 2. Options 3 through 9 allow modifications to this input file after it has been created.

Option (3):

Title — A title of up to 80 characters that will appear on the top of all pages of output.

Option (4):

Site index — The site index for the stand based on sugar maple at age 50 (40 to 80).

Option (5):

Initial stand

Trees per acre — The average number of trees per acre in the initial stand (25 to 1,500).

Basal area — The initial basal area in square feet per acre (20 to 130).

Mean stand diameter — The quadratic mean stand diameter to the nearest tenth of an inch (4.0 to 16.0).

Option (6):

Initial composition — The initial species composition of the stand by eight species groups and three quality classes. The species groups are: beech (BE), yellow birch (YB), sugar maple (SM), red maple (RM), paper birch-aspen (PBA), white ash (WA), conifer (CON), and other (OTH). The three quality classes are to be defined by the user. The total composition for the 24 entries must equal 100 percent.

Option (7):

Thinning

Type — (0) - no thinning will be done.
(1) - thin when the stand reaches the A line of the stocking chart (Fig. 1).
<2> - thin at a user specified level above the B line. This value must be between 5 and 40 square feet.

When — The user-specified quadratic mean stand diameter must be reached before the first thinning will occur. After the first thinning, control will be according to the option selected above.

Residual level — <1> - thin to the B line.
(2) - for stands with a quadratic mean stand diameter less than 6.0 inches the stand will be thinned to a quality line (Fig. 1) at 80 square feet. For stands over 6.0 inches, the residual level will be given by the B line.

Order of removal — The eight species and three quality classes are numbered from 1 to 24 in the following manner:

	Species							
Quality Class	BE	YB	SM	RM	PBA	WA	CON	OTH
1	1	2	3	4	5	6	7	8
2	9	10	11	12	13	14	15	16
3	17	18	19	20	21	22	23	24

The user is asked to list these numbers in the order that they want the species-quality classes removed. The default order is: 24, 20, 17, 23, 18, 19, 21, 22, 16, 12, 9,

15, 13, 14, 10, 11, 8, 4, 1, 7, 5, 6, 2, 3. All numbers should be entered or the remaining default order will be used.

Thin split — A number from 1 to 24 is specified that represents a position within the removal order (that is, thin split = 12, refers to species quality group 15 above, the 12th entry in the priority list). All species-quality groups prior to this entry will be removed entirely until the residual level is obtained, while for the groups after this entry, only an amount proportional to the amount of the species group in the stand will be removed.

Paper birch — Paper birch and aspen mortality is increased between years 80 and 100 until all of both species are removed. There is an option which will allow the user to salvage this mortality if desired.

(0) - For any thinning after the stand is 70 years old, the model will automatically give highest priority of removal to paper birch and aspen for salvage.

<1> - The priorities remain as entered, thereby maintaining the user-specified order of removal.

Option (8):

Rotation

Rotation age — The age at which the final harvest is to occur.

Harvest diameter — The quadratic mean stand diameter of final harvest. The final harvest will be at rotation age or harvest diameter, whichever occurs first.

Report interval — A summary of the stand characteristics will be sent to the user-specified output. This summary includes the basal area, number of trees per acre, and quadratic mean stand diameter.

Option (9):

Random number — The random number generator within the model requires a nine-digit odd integer to begin.

Option (10):

Display file — A summary of the input data will be displayed on the console.

Option <11>:

Execute — Simulation begins using the criteria contained in the input data file.

An example of creating the input data file and the subsequent simulation is shown in Table 4. As with SIMSAP, all data may be entered free-format and are shown in italics in the table. At the end of the simulation the user is asked if the yields are to be displayed. A yes (Y) response will cause the standing yield, sum of thinning yields, and total yield to be printed on the console and simultaneously go to the primary output device. The program waits for a carriage return between tables. Next, the user is asked if they wish to run another simulation with this stand. If the answer is Y, the program returns to the menu. If the answer is no <N>, the user is asked if a simulation with a new input data file is desired. A Y response will return the user to entering a file name for the input file and a designation for the output. An N response will cause termination of the program.

SIMTIM Output

The output of SIMTIM (Table 4) is made up of a copy of the input data, intermediate reports of stand characteristics, intermediate thinning reports, and a final harvest report. At user-specified intervals, reports of the stand age; quadratic mean stand diameter; number of trees in the stand, at the A and B line; basal area of the stand, at the A and B line; and the percent sawtimber are all printed.

When a thinning occurs, the age of the stand and the stand characteristics are given. Also presented are the number of trees thinned, the basal area removed, and a yield table by species and quality class showing the percent removed, square feet of basal area, cubic-foot volume and board-foot volume.

At the final harvest, a summary of the stand conditions is printed along with the standing yield, the total yield from all thinnings, and the sum of the standing yield plus all thinnings. These yields are presented by species and quality class in units of square feet of basal area, cubic-foot volume, and board-foot volume.

Square feet of basal area is converted to both cubic feet and board feet based on the quadratic mean stand diameter and site index (Leak 1980). Thus, the yields by species are based on the percentage of a species in the total basal area. The cubic feet per square foot of basal area give the total cubic feet; similarly, the board feet per square foot give the board feet. Then the board feet divided by the board feet/cubic feet ratio gives the amount of cubic feet in the sawtimber yields. By subtracting this amount from the total yield, we can estimate the amount of cubic feet in pulp, cull, or extra sawtimber.

The computer programs described in this publication are available on request with the understanding that the U.S. Department of Agriculture cannot assure their accuracy, completeness, reliability, or suitability for any other purpose than that reported. The recipient may not assert any proprietary rights thereto nor represent it to anyone as other than a Government-produced computer program. For information, please write: Dr. Dale S. Solomon, USDA Building, University of Maine, Orono, ME, 04473.

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Table 3. — Sample run for SIMSAP, Version 2.0. Items in italics are entered by the user

SIMSAP
Please enter input file name:
SAP.CTL
Is input file <1> old or (2) new?
2

(1) HELP	(7) PRUNING
(2) NEW FILE	(8) RANDOM #
(3) TITLE	(9) # REPEAT RUNS
(4) INITIAL STAND	(10) DISPLAY FILE
(5) SITE INDEX	(11) OUTPUT
(6) WEEDING	<12> EXECUTE

2
Enter title:
SAMPLE RUN OF SIMSAP
Enter percent composition of initial stand:

BE	YB	SM	RM	PB	WA	PC	STMAP	ASP	OTH	RMSP
8	*12*	*16*	*5*	*16*	*2*	*18*	*2*	*3*	*8*	*10*

Site index:
60
Is weeding desired?
Y
Enter the diameter at which to begin weeding (1.0 to 3.0):
2.5
Maximum number of acceptable stems:
3500
Minimum number of acceptable stems:
400
Number of crop trees released per acre:
400
Average number of competitors removed per crop tree:
2
Priority of removal from 1 to 6 (zero for not a crop tree):

BE	YB	SM	RM	PB	WA
0	*5*	*6*	*1*	*2*	*3*

(1) No pruning
<2> Prune YB and SM
<cr>
Random number:
987654321
# of repeat runs:
1

(1) HELP	(7) PRUNING
(2) NEW FILE	(8) RANDOM #
(3) TITLE	(9) # REPEAT RUNS
(4) INITIAL STAND	(10) DISPLAY FILE
(5) SITE INDEX	(11) OUTPUT
(6) WEEDING	<12> EXECUTE

11
INPUT DATA
SAMPLE RUN OF SIMSAP
Species comp:

BE	YB	SM	RM	PB	WA	PC	STMAP	ASP	OTH	RMSP
.08	.12	.16	.05	.16	.02	.18	.02	.03	.08	.10

Site index = 60.0
Weeding desired at d.b.h. 2.5

Acceptable stems		Crop trees	Competitors
min	max	released	removed
400.	3500.	400.	2.

Priority:

BE	YB	SM	RM	PB	WA
0.	5.	6.	1.	2.	3.

YB and SM will be pruned
Random number: 987654321
# of repeat runs: 1

SAMPLE RUN OF SIMSAP
Number of yellow birch pruned = 47.4
Number of sugar maple pruned = 19.4
Weeding was applied at 2.5 d.b.h.

Crop trees of	BE	YB	SM	RM	PB	WA	ALL
	.0	75.4	41.0	45.9	185.0	26.4	373.6

Number cut in weeding = 747.3 Number left = 1541.9
2-INCH CLASS DROPPED
*****

END OF SAPLING STAGE:

# TREES	BASAL AREA	AVG DBH	YEARS
769.1	85.8	4.5	38.0

NUMBER AND PERCENT OF TREES
COMMERCIAL SPECIES

POTENTIAL		BE	YB	SM	RM	PB	WA
QUALITY 1	#	0.7	26.5	41.0	7.0	48.9	6.0
(VENEER)	%	0.1	3.4	5.3	0.9	6.4	0.8
QUALITY 2	#	1.2	0.0	5.8	9.1	93.6	3.2
(SAWLOG)	%	0.2	0.0	0.8	1.2	12.2	0.4
QUALITY 3	#	13.0	57.2	21.3	20.7	127.8	6.6
(BULK)	%	1.7	7.4	2.8	2.7	16.6	0.9

NON-COMMERCIAL SPECIES

	RMSP	ASP	OTH	STMAP	PC
#	133.9	33.6	89.5	22.4	0.0
%	17.4	4.4	11.6	2.9	0.0

Do you want another run with this data file?
N
Do you want to use another data file?
<cr>
Stop - Program terminated.

Table 4. — Sample run of SIMTIM Version 2.0 showing the first of 6 thinnings. Items in italics are entered by the user

SIMTIM

Please enter input file name:
TIM.CTL
Is input file <1> old or (2) new?
2

(1) HELP	(7) THINNING
(2) NEW FILE	(8) ROTATION
(3) TITLE	(9) RANDOM #
(4) SITE INDEX	(10) DISPLAY FILE
(5) INITIAL STAND	(11) OUTPUT
(6) INITIAL COMPOSITION	<12>EXECUTE

2
Enter title:
SAMPLE RUN OF SIMTIM
Site index:
60
Average number of trees/acre:
1050
Enter the basal area:
91.0
Mean stand diameter:
4.0
Age of stand:
30

Species composition and quality class

	BE	YB	SM	RM	PBA	WA	CON	OTH
Class 1	*7*	*23*	*22*	*1*	*5*	*1*	*0*	*0*
Class 2	*4*	*11*	*11*	*0*	*3*	*1*	*0*	*0*
Class 3	*1*	*4*	*4*	*0*	*1*	*0*	*0*	*1*

(0) - No thinning
(1) - Thin when stand reaches A line
<2> - Thin at user-specified level above B line (in ft^2)
<cr>
Please enter the amount of square feet above the B line to start thinning:
30
Do you wish to:
<1> thin to the B line for all diameters or
(2) thin to 80 ft^2 up to stand diameter 6 and then to the B line?
2

Species composition and quality class

		BE	YB	SM	RM	PBA	WA	CON	OTH
1	%	7.0	23.0	22.0	1.0	5.0	1.0	0.0	0.0
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
2	%	4.0	11.0	11.0	0.0	3.0	1.0	0.0	0.0
		(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
3	%	1.0	4.0	4.0	0.0	1.0	0.0	0.0	1.0
		(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)

Current species removal order:
< 24 20 17 23 18 19 21 22 16 12 9 15 13 14 10 11 8 4 1 7 5 6 2 3 >
Choose current species removal order:
<cr>
Please enter the thinning split number. Species that occur after this number in the species removal array will be thinned according to their proportion of the stand composition. 24 MEANS NO PROPORTIONAL THINNING WILL OCCUR.
<24>
17
Paper Birch removal:
(0) - paper birch and aspen are removed first in thinning after age 70
<1> - operator specified removal order
0
Beginning thinning diameter:
5.0
Rotation age:
200
Harvest diameter of the stand:
18.0
Report interval in years:
<1>
200

Random number:
987654321

(1) HELP	(7) THINNING
(2) NEW FILE	(8) ROTATION
(3) TITLE	(9) RANDOM #
(4) SITE INDEX	(10) DISPLAY FILE
(5) INITIAL STAND	(11) OUTPUT
(6) INITIAL COMPOSITION	<12> EXECUTE

<cr>
INPUT DATA
TEST OF SIMTIM
Site index = 60.0
Number of trees/acre = 1050.0
Basal area/acre = 91.0
Quadratic mean diameter = 4.0
Age of stand = 30.0

QUALITY CLASS		SPECIES BE	YB	SM	RM	PBA	WA	CON	OTH	TOTAL
1	%	7.0	23.0	22.0	1.0	5.0	1.0	0.0	0.0	59.0
	FT2	6.4	20.9	20.0	0.9	4.6	0.9	0.0	0.0	53.7
2	%	4.0	11.0	11.0	0.0	3.0	1.0	0.0	0.0	30.0
	FT2	3.6	10.0	10.0	0.0	2.7	0.9	0.0	0.0	27.3
3	%	1.0	4.0	4.0	0.0	1.0	0.0	0.0	1.0	11.0
	FT2	0.9	3.6	3.6	0.0	0.9	0.0	0.0	0.9	10.0

Thin when stand reaches 30 ft² above the B line and mean stand diameter is at least 5.0 inches.
Quality-line thinning (thin to 80 ft²) will be used up to diameter 6 inches.
Order of species class removal by priority:

24	20	17	23	18	19	21	22	16	12	9	15
13	14	10	11	8	4	1	7	5	6	2	3

Thinning split number: 17
Model starts to remove paper birch and aspen first in thinnings after age 70
Rotation age: 200.
Harvest diameter: 18.0
Report interval: 200
Random number: 987654321

TEST OF SIMTIM
Thinning #1
Stand at 45 years

	Stand	A line	B line
Diameter	5.5		
# trees	635.5	635.5	355.6
Sq. ft.	104.0	103.9	58.1

Percent sawtimber = 0.
Thinning yields
Number of trees thinned = 147.2
BA thinned = 24.1

QUALITY		SPECIES								
CLASS		BE	YB	SM	RM	PBA	WA	CON	OTH	TOTAL
1	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	FT2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	FT3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	BF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	%	3.8	2.7	0.0	0.0	4.3	1.3	0.0	0.0	12.0
	FT2	4.0	2.8	0.0	0.0	4.4	1.3	0.0	0.0	12.5
	FT3	57.0	39.7	0.0	0.0	63.2	18.7	0.0	0.0	178.6
	BF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	%	1.0	3.9	3.6	0.0	1.4	0.0	0.0	1.2	11.1
	FT2	1.0	4.0	3.8	0.0	1.5	0.0	0.0	1.3	11.6
	FT3	14.3	57.6	54.1	0.0	21.1	0.0	0.0	17.9	164.9
	BF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TEST OF SIMTIM
STAND AT HARVEST
Site index = 60.0
Number of trees/acre = 49.2
Basal area = 87.8
Quadratic mean diameter = 18.0
Age of stand = 122.
Thinning began at diameter 5.0

HARVEST YIELD

QUALITY		SPECIES								
CLASS		BE	YB	SM	RM	PBA	WA	CON	OTH	TOTAL
	%	15.2	37.6	40.8	3.3	0.0	3.2	0.0	0.0	100.0
	FT2	13.3	33.0	35.8	2.9	0.0	2.8	0.0	0.0	87.8
1	FT3	357.3	883.9	959.9	77.1	0.0	75.4	0.0	0.0	2353.6
	BF	1501.9	3715.0	4034.4	324.0	0.0	316.8	0.0	0.0	9892.1
	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	FT2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	FT3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	BF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	FT2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	FT3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	BF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TOTAL YIELD FROM THINNINGS

QUALITY		SPECIES								
CLASS		BE	YB	SM	RM	PBA	WA	CON	OTH	TOTAL
	FT2	15.0	40.4	41.6	3.3	17.3	3.2	0.0	0.0	120.8
1	FT3	340.6	900.0	937.4	74.8	342.9	73.1	0.0	0.0	2668.9
	BF	1125.7	2883.8	3066.1	246.7	852.8	241.0	0.0	0.0	8416.0
	FT2	4.0	12.0	11.6	0.0	4.4	1.3	0.0	0.0	33.3
2	FT3	57.0	177.7	173.8	0.0	63.2	18.7	0.0	0.0	490.5
	BF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	FT2	1.0	4.0	3.8	0.0	1.5	0.0	0.0	1.3	11.6
3	FT3	14.3	57.6	54.1	0.0	21.1	0.0	0.0	17.9	164.9
	BF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TOTAL YIELD

QUALITY		SPECIES								
CLASS		BE	YB	SM	RM	PBA	WA	CON	OTH	TOTAL
	FT2	28.3	73.3	77.4	6.2	17.3	6.0	0.0	0.0	208.6
1	FT3	698.0	1783.9	1897.3	151.9	342.9	148.5	0.0	0.0	5022.5
	BF	2627.6	6598.7	7100.5	570.6	852.8	557.8	0.0	0.0	18308.0
	FT2	4.0	12.0	11.6	0.0	4.4	1.3	0.0	0.0	33.3
2	FT3	57.0	177.7	173.8	0.0	63.2	18.7	0.0	0.0	490.5
	BF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	FT2	1.0	4.0	3.8	0.0	1.5	0.0	0.0	1.3	11.6
3	FT3	14.3	57.6	54.1	0.0	21.1	0.0	0.0	17.9	164.9
	BF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

THE TOTAL HARVEST PER ACRE (INCLUDING THINNINGS) IS:

BASAL AREA: 253.4
CUBIC FEET: 5677.9
BOARD FEET: 18308.0

Solomon, Dale S.; Hosmer, Richard A. 1987. **User's guide for the northern hardwood stand models: SIMSAP and SIMTIM.** Res. Pap. NE-606. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 13 p.

SIMSAP and SIMTIM are computer programs that have been developed to simulate the stand growth and development of natural and treated even-aged northern hardwood stands. SIMSAP begins with species distributions by quality classes in sapling stands after regeneration. SIMTIM, the poletimber-sawtimber-harvest phase, uses stocking guides based on quadratic mean stand diameter, number of trees, and basal area per acre of trees in the main crown canopy. Using available data, the connecting phases of the models have been tested to determine the effects of silvicultural treatments (or no treatment) on long-term stand response. The models are coded in FORTRAN 77 and are available on mainframe and IBM compatible microcomputers with a minimum of 256 K.

ODC. 181.65, 228.5, 228.82
Keywords: Growth model, Northern hardwoods, even-aged

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Research Paper NE-607

Abundance and Distribution of Vegetation under Four Hardwood Stands in North-Central West Virginia

G. W. Wendel

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Abstract

Forest floor samples were collected from four hardwood forest stands in West Virginia to study species composition, abundance, and distribution of vegetation that originated from seeds, rootstocks, rhizomes, and so on. The abundance and distribution of plants on square-foot sections of forest floor that were lifted and moved to the greenhouse indicate that under the most ideal conditions upwards of 800,000 stems per acre may occur during the first year. Sweet birch was the most abundant tree species, blackberry the most abundant shrub, and species of violets were the most abundant herbaceous plants. Implications of this vegetation on the regeneration of the forest are discussed.

The Author

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Introduction

Control of species composition is a major regeneration problem in central Appalachian hardwood forests. After harvest cutting, dense stands of tree seedlings, shrubs, vines, and herbaceous plants become established. The species composition of the future forest is often determined at this time. The situation is further confounded by variation in the silvical requirements and relative desirability of tree species, changes in site quality over short distances, and the destruction of tree seeds by birds, mammals, insects, and diseases. Slower growing desirable species such as newly germinated oak seedlings are often overtopped by less desirable plant species that make it difficult to bring the oak through. This paper presents estimates of the quantity and distribution of species that were observed in 12-inch x 12-inch x 4-inch samples of forest floor from four hardwood stands on two areas with different site indexes. These data provide an insight to the competition problem and serve as a basis for designing studies to cope with it.

The Study Area

All of the forest floor sampling was done on 1/2-acre growth plots that were established earlier as part of the Fernow Experimental Forest growth study. The Fernow Experimental Forest is a 5,000-acre outdoor laboratory of the Northeastern Forest Experiment Station located in Tucker County near Parsons, West Virginia. Two forested areas encompassing three site index classes were sampled. Area I is about 39 acres of undulating, relatively flat land at an average elevation of about 2,300 feet. Area II approximately 80 acres in size has moderately steep topography with slopes mostly between 20 and 40 percent. Elevation on Area II ranges between 1,800 and 2,500 feet.

Average oak site index (Trimble and Weitzman 1956) for Area I, which varied little in topography and soil, was 70. Area II varied widely in site index and was divided into three oak site index strata: 64, 70, and 80.

The soils on both areas are silt loams derived from acid sandstone and shale from the Mauch Chunk and Pocono geologic formation. Calvin channery silt loam, a loamy-skeletal, mixed mesic Typic Dystrochrepts, is the predominant soil on both areas with scattered areas of Dekalb silt loam, a loamy-skeletal mixed mesic Typic Dystrochrepts near the ridge tops. Both soils are moderately well-drained and 2 to 4 feet deep to bedrock.

Precipitation averages 58 inches annually and is well distributed throughout the year. The average length of the frost-free season is about 145 days.

The existing forest is composed of second growth hardwood timber that came in after the cutting during the early 1900's, old residual trees of species that were in low demand during the early cutting, and trees that became established as the American chestnut died in the 1930's.

The three stands on Area II were stratified by oak site index. The site index 80 area is typical of Society of American Foresters (SAF) cover type 59—yellow-poplar—white oak—northern red oak (Eyre 1980) (Table 1). This type includes a large component of yellow-poplar, white oak, and northern red oak. At lower elevations black locust, white ash, and other mesic site species may be present. At higher elevations, American beech, red and sugar maple, and other species may become more abundant. The site index 64 and 70 areas are more typical of SAF cover type 55—northern red oak. On the more moist sites a rather large component of yellow-poplar, black cherry, sugar maple, beech, white ash, and white oak may be present. On drier sites, other oaks, hickories, black gum, and red maple may be more abundant.

Methods

On Area I, ten 1/2-acre square growth plots were sampled. Forest floor samples were 12-inches square and were lifted from 16 locations established on a 25- by 25-foot grid in each growth plot, 160 samples in all. On Area II, two 1/2-acre circular growth plots were sampled in each site index stratum. Twenty forest floor samples were lifted from five locations at 15-foot intervals on each cardinal direction from plot center in each plot, 40 samples from each site index strata. Because of greenhouse space limitations, Area II samples were collected in November 1982, and Area I samples were lifted in November 1983.

Forest floor samples were carefully cut with a machete to a depth of 4 inches around the inside of a wooden template. The sample trays were constructed of wood, 12-inches x 12-inches x 4-inches, with a 1/4-inch mesh hardware cloth bottom. The cut block of forest floor was carefully lifted with a spade and placed in a tray. Where stoniness prevented lifting the sample intact, the sample was carefully gathered with a trowel and placed in a tray. Usually a single layer of leaves was placed on the hardware cloth bottom in the tray to prevent soil sifting during transport of the samples.

The samples were labeled as to location and plot and randomly placed on greenhouse benches. No heat was maintained in the greenhouse during the winter, but flats were watered occasionally when the soil looked dry. About mid-March the automatic overhead watering system was started. Water was applied through a misting system for 2 hours each morning, and the greenhouse was heated to keep the flats from freezing during the early spring. Seeds that ger-

Table 1.—Average number and average basal area, ft^2/acre, of stems larger than 1.0 inch d.b.h. in the four stands sampled

Species	Area I		Area II					
	Site Index 70		Site Index 64		Site Index 70		Site Index 80	
	Number	Basal area	Number	Basal area	Number	Basal area	Number	Basal area
Eastern hemlock	14	4	—	—	—	—	—	—
Sweet birch	7	3	15	1	—	—	8	2
White oak	22	35	24	27	1	4	3	8
Chestnut oak	15	17	34	35	—	—	2	2
Red oak	18	30	52	33	18	50	19	44
Cucumbertree	5	5	10	1	—	—	7	5
Fraser magnolia	14	4	6	<1	—	—	—	—
Yellow-poplar	3	3	—	—	1	2	17	25
Black locust	3	2	—	—	4	3	—	—
Sugar maple	8	4	—	—	249	46	220	14
Red maple	38	13	171	14	34	9	70	18
Sourwood	25	13	28	10	—	—	—	—
Hickories	—	—	—	—	5	4	12	5
American beech	—	—	55	2	—	—	6	<1
Downy serviceberry	—	—	81	2	—	—	8	<1
Black cherry	—	—	—	—	39	46	14	6
American basswood	—	—	—	—	6	1	12	7
White ash	—	—	—	—	8	6	8	7
American chestnut	—	—	19	<1	—	—	—	—
Scarlet oak	—	—	6	10	—	—	—	—
Sassafras	—	—	4	1	—	—	—	—
Black gum	—	—	29	5	—	—	—	—
Dogwood	—	—	—	—	—	—	10	<1
Striped maple	—	—	—	—	—	—	3	<1
Eastern hophornbeam	—	—	—	—	12	1	—	—
Slippery elm	—	—	—	—	3	2	—	—
Total	172	133	534	143	380	174	419	147

minated and/or root stocks that sprouted were allowed to grow until mid-September after which time species in each tray were identified, counted, and the number recorded by tray.

Results

Forty-four plant species were identified in the trays at the end of the study. A few sparsely occurring grasses and sedges were observed in the trays but were not identified.

Tree Species

Sweet birch was by far the most abundant and frequent of the nine tree species observed in all of the trays (Table 2). Numbers ranged from 126,000 per acre to more than 450,000 per acre with a frequency—percentage of flats containing at least one sweet birch—ranging from 68 to 98 percent. On the three Area II sites, sweet birch was most abundant in the trays that were collected from the site index 64 site.

Yellow-poplar was the second most abundant species. Projected field abundance was estimated at more than 100,000 seedlings per acre on the oak site index 80 area and about 23,000 per acre on the site index 64 area. Yellow-poplar frequency ranged from 73 percent on site index 80 to 40 percent on the site index 64 area.

Table 2.—Projected average number of tree seedlings (thousand/acre)[a] and frequency[b] of occurrence in forest floor samples collected at four locations in West Virginia

Species	Area I		Area II					
	Site Index 70		Site Index 64		Site Index 70		Site Index 80	
	Number	Frequency	Number	Frequency	Number	Frequency	Number	Frequency
Sweet birch	450	98	320	98	126	68	170	88
Yellow-poplar	89	73	23	40	48	50	101	73
Sourwood	36	31	74	68	—	—	1	3
Sassafras	22	29	70	73	1	3	4	5
Fire cherry	10	15	—	—	—	—	—	—
Red oak	2	5	6	5	1	3	—	—
Black locust	2	5	—	—	1	3	1	3
Fraser magnolia	2	2	—	—	—	—	—	—
Red maple	1	1	8	18	—	—	—	—
Sugar maple	—	—	—	—	—	—	1	3
Black cherry	—	—	4	5	9	15	5	3
Total	614	—	505	—	186	—	283	—

[a] Rounded to nearest 1,000.
[b] Percentage of flats with at least one seedling.

Sassafras also occurred in trays from all sites but was most abundant and well distributed on the site index 64 area—70,000 per acre with 73 percent frequency. Sassafras was also abundant on Area I site index 70, but its occurrence was considerably less than that in the trays from the Area II site index 64. Sassafras frequency was low in the trays from Area II, site index 70 and 80.

Red oak seedlings ranged from about 1,000 to more than 6,000 per acre on areas with site index 64 and 70. No red oaks were observed in the trays from the site index 80 area. Seedling frequency in trays from the site index 64 and 70 areas ranged from 3 to 5 percent. A heavy population of red squirrels, chipmunks, and other rodents was observed on both areas, and most of the uneaten acorns were observed to be weevil infested.

Sourwood abundance averaged between 36,000 and 74,000 seedlings per acre in the trays from site index 64, Area II and site index 70, Area I. Frequency ranged from 31 to 68 percent.

Other tree species that emerged in the trays were fire cherry, black locust, Fraser magnolia, red maple, sugar maple, and black cherry. Most of these were poorly distributed occurring in only a small percentage of the trays.

Semi-woody and shrub species

Of the nine shrub species identified in the flats, the most abundant was blackberry. Blackberry stems ranged from about 100,000 per acre to more than 200,000 per acre (Table 3). Frequency ranged from 73 to 88 percent of the trays. Blackberry was the most abundant in trays from the two site index 70 areas and least abundant in those from site index 64.

Wild grape was the second most abundant species in this class. The number of wild grape ranged from 5,000 to 100,000 seedlings per acre. Trays from the site index 64 area contained fewer wild grape seedlings than those from the site index 70 or 80 sites. Frequency ranged from 8 percent for trays from the site index 64 area to 61 percent for the trays from the higher site index areas.

Table 3.—Projected average number of shrub and semi-woody stems (thousand/acre)[a] and frequency[b] of occurrence in forest floor samples collected at four locations in West Virginia

Species	Area I		Area II					
	Site Index 70		Site Index 64		Site Index 70		Site Index 80	
	Number	Frequency	Number	Frequency	Number	Frequency	Number	Frequency
Striped maple	1	3	2	3	—	—	—	—
Devils-walkingstick	29	41	19	23	5	10	5	10
Blackberry	153	75	104	73	220	88	139	78
Wild grape	100	61	5	8	30	28	41	50
Flame azalea	—	—	14	23	3	8	—	—
Teaberry	—	—	88	13	—	—	—	—
Blueberry	—	—	12	3	—	—	—	—
Flowering dogwood	—	—	1	3	—	—	—	—
Total	283	—	245	—	258	—	185	—

[a] Rounded to nearest 1,000.
[b] Percentage of flats with at least one seedling.

Devils-walkingstick was abundant in the trays from the site index 64 and 70 (Area I) areas (Table 3). Frequency was 41 and 23 percent, respectively, for the two sites. On Area II, site index 70 and 80, there were fewer stems per acre and only 10 percent of the trays contained devils-walkingstick. Many of the other shrubs observed—teaberry, blueberry, azalea and flowering dogwood—were restricted to the site index 64 area. The most abundant was teaberry.

Herbaceous Species

Twenty-seven species of forbs, grasses, and ferns were identified in the flats. Sparse amounts of other grasses and sedges were not identified.

Species of violets were the most abundant and well distributed in the trays from the better sites (Table 4). Field estimates ranged from 34,000 to about 169,000 stems per acre. Violet frequency ranged from 39 to 80 percent in the trays from the site index 70 and 80 areas, compared to 20 percent in the trays from the area with site index 64.

Other common species that occurred on all sites were plantainleaf sedge, mountain spleenwort, pokeweed, and common cinquefoil. Knotweed occurred only in the trays from Area II, site index 64. Among the species occurring in trays from the two better sites in Area II were enchanters-nightshade, white snakeroot, two-leaved toothwort, Indian tobacco, wild stonecrop, cleavers, and wood nettle. There were more herbaceous species in Area I trays from site index 70 than there were from Area II samples, which also had an oak site index of 70.

Discussion

When forest stands in the Central Appalachians are disturbed by clearcutting, fire, or mechanical site preparation, rapid revegetation of the areas usually occurs (Kochenderfer and Wendel 1983; Wendel and Trimble 1968). Numerous observations on clearcut areas show that by the end of the second growing season site occupancy is usually attained. The potential for more than 800,000 stems per acre to become established in the first year as estimated from the observations in this study lends credence to the statement that "nature abhors a vacuum." In natural ecosystems that are scheduled to be managed, this can lead to problems. On the one hand, site stability is rapidly restored and on the other, an abundance of undesirable species often creates drastic and costly control procedures.

Table 4.—Projected average number of herbaceous plants (thousand/acre) and frequency[a] of occurrence in forest floor samples collected at four locations in West Virginia

Species	Area I		Area II					
	Site Index 70		Site Index 64		Site Index 70		Site Index 80	
	Number	Frequency	Number	Frequency	Number	Frequency	Number	Frequency
Plantainleaf sedge	47	39	1	3	13	20	14	23
Violet	34	31	6	20	169	80	87	70
Mountain spleenwort	33	56	11	40	6	33	4	15
Pokeweed	12	21	4	15	28	28	8	3
Common cinquefoil	10	12	12	15	17	15	5	3
Upright yellow wood sorrel	7	9	—	—	21	23	1	3
Deertongue grass	2	5	2	3	—	—	2	5
Fireweed	3	6	1	3	2	5	—	—
Woodnettle	—	—	—	—	140	75	57	40
Richweed	<1	1	—	—	24	5	—	—
Shield fern	8	5	—	—	—	—	—	—
Whorled loose strife	6	7	—	—	—	—	—	—
Wild yam	1	3	—	—	—	—	1	3
Enchanters-nightshade	—	—	—	—	2	5	1	3
White snakeroot	—	—	—	—	5	13	—	—
Two-leaved toothwort	—	—	—	—	1	3	19	10
Virginia avens	—	—	—	—	1	3	—	—
Indian tobacco	—	—	—	—	1	5	13	18
Wild stonecrop	—	—	—	—	25	25	1	3
Buttercup	—	—	—	—	2	5	—	—
Dodder	—	—	—	—	1	13	—	—
Cleavers	—	—	—	—	—	—	2	5
Trillium	—	—	—	—	—	—	3	8
Knotweed	—	—	2	3	—	—	—	—
Wild cranesbill	—	—	—	—	1	3	—	—
Total	164	—	39	—	459	—	218	—

[a] Percentage of flats with at least one seedling.

The important aspect is that ground cover is quickly established and that the loss in soil and nutrients is curtailed by plant roots and recycling of nutrients through the plants. Marks (1974) has emphasized the importance of early successional species such as fire cherry in accomplishing this. Similarly, the large number and wide distribution of sweet birch, yellow-poplar, blackberry, wild grape, and devils-walkingstick observed in the flats perform the same role in the natural environment. Sweet birch seedlings probably arose from seeds disseminated the previous winter, whereas much of the yellow-poplar, blackberry, wild grape, devils-walkingstick, arose from seed stored in the forest floor. Studies have shown that wild grape, yellow-poplar, black cherry, and sassafras seeds are known to retain their viability in the forest floor for several to many years (Clark and Boyce 1964; Wendel 1977, 1981).

Numerous grasses and forbs were identified in the flats. Some of these may have originated from seed stored for relatively long periods but this was not determined. Other species probably are biennials or perennials that are components of the spring or summer flora and originated from existing rootstocks.

The impact of herbaceous plants on tree reproduction in central Appalachian forests is not well understood. However, it has been shown in other areas that plant antagonisms exist between and among many species. With such a large and varied flora encountered in this study, there are undoubtedly some allelopathic relationships. Many studies in different areas support this contention (Horsley 1977; Fisher et al. 1978; Gabriel 1975; Tubbs 1973, 1976; Hook and Stubbs 1967).

The immediate effect of early and rapid natural revegetation of disturbed forest sites is site stabilization. Over the longer term, however, regeneration of forest stands may be delayed or seriously curtailed. A knowledge of the potential species mix for various sites and parent stand compositions can provide the forest manager with insight to this problem and highlight specific areas where preharvest treatment and research might be needed.

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List of Species Mentioned in this Paper

Tree Species

Common Name	Scientific Name
American basswood	*Tilia americana* L.
American beech	*Fagus grandifolia* Ehrh.
American chestnut	*Castanea dentata* (Marsh.) Borkh.
Black cherry	*Prunus serotina* Ehrh.
Black gum	*Nyssa sylvatica* Marsh.
Black locust	*Robinia pseudoacacia* L.
Chestnut oak	*Quercus prinus* L.
Cucumbertree	*Magnolia acuminata* L.
Downy serviceberry	*Amelanchier arborea* (Michx.f.) Fern.
Eastern hemlock	*Tsuga canadensis* (L.) Carr.
Eastern hophornbeam	*Ostrya virginiana* (Mill.) K.Koch
Fire cherry	*Prunus pensylvanica* L. f.
Flowering dogwood	*Cornus florida* L.
Fraser magnolia	*Magnolia fraseri* Walt.
Hickories	*Carya* sp. Nutt.
Red maple	*Acer rubrum* L.
Sugar maple	*Acer saccharum* Marsh.
Northern red oak	*Quercus rubra* L.
Sassafras	*Sassafras albidum* (Nutt.) Nees
Scarlet oak	*Quercus coccinea* Muenchh.
Slippery elm	*Ulmus rubra* Muhl.
Sourwood	*Oxydendrum arboreum* (L.) DC.
Striped maple	*Acer pensylvanicum* L.
Sweet birch	*Betula lenta* L.
White ash	*Fraxinus americana* L.
White oak	*Quercus alba* L.
Yellow-poplar	*Liriodendron tulipifera* L.

Shrubs and Herbaceous Vegetation

Common Name	Scientific Name
Blackberry	*Rubus* sp.
Blueberry	*Vaccinium* spp. L.
Buttercup	*Ranunculus* L. spp.
Cleavers	*Galium Aparine* L.
Common cinquefoil	*Potentilla simplex* Michx.
Common dodder	*Cuscuta gronovii* Willd.
Deertongue grass	*Panicum clandestinum* L.
Devils-walkingstick	*Aralia spinosa* L.
Enchanters-nightshade	*Circaea quadrisulcata (Maxim.)* Franch. and Sav.
Fireweed	*Erechtites hieracifolia* L. Raf.
Flame azalea	*Rhododendron calendulaceum* (Michx.) Torr.
Indian tobacco	*Lobelia inflata* L.
Knotweed	*Polygonum* spp. L.
Mountain spleenwort	*Asplenium montanum* Willd.
Plantainleaf sedge	*Carex plantaginea* Lam.
Pokeweed	*Phytolacca americana* L.
Richweed	*Pilea pumila* (L.) Gray
Shield fern	*Dyropteris spinulosa* (O.F.Muell.) Watt
Teaberry	*Gaultheria procumbens* L.
Trillium	*Trillium* L. spp.
Two-leaved toothwort	*Dentaria diphylla* Michx.
Upright yellow wood sorrel	*Oxalis structa* L.
Violets	*Viola* spp. L.
Virginia avens	*Geum virginianum* L.
White snakeroot	*Eupatorium rugosum* Houtt.
Whorled loosestrife	*Lysimachia quadrifolia* L.
Wild cranesbill	*Geranium maculatum* L.
Wild grape	*Vitis* L. spp.
Wild stonecrop	*Sedum ternatum* Michx.
Wild yam	*Dioscorea villosa* L.
Woodnettles	*Laportea canadensis* (L.) Wedd.

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Forest floor samples were collected from four hardwood forest stands in West Virginia to study species composition, abundance, and distribution of vegetation that originated from seeds, rootstocks, rhizomes, and so on. The abundance and distribution of plants on square-foot sections of forest floor that were lifted and moved to the greenhouse indicate that under the most ideal conditions upwards of 800,000 stems per acre may occur during the first year. Sweet birch was the most abundant tree species, blackberry the most abundant shrub, and species of violets were the most abundant herbaceous plants. Implications of this vegetation of the regeneration of the forest are discussed.

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Research Paper NE-608

Changes in Hardwood Growing-Stock Tree Grades

David L. Sonderman
Everette D. Rast

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Abstract

Describes changes in provisional tree grades for 351 young, mixed upland hardwood trees 6 years after thinning. Treatments of 30, 50, and 70 percent stocking plus a crop-tree release were applied. Results indicate that light thinning and crop-tree thinning produced higher quality and better grade trees than heavy thinning.

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November 1987

Introduction

The United States has an estimated 230 billion cubic feet of hardwood growing-stock volume. With this much raw material, some measure of potential quality and associated grade change is needed to eventually predict the value. But to do this, we must first: (1) identify the potential quality trees, and (2) determine the type of cultural treatment needed to produce good-quality growth in the future. Recognizing these requirements, Boyce and Carpenter (1968) developed provisional grade specifications for young hardwood growing-stock trees. The grade specifications were assigned according to the probability of a young tree yielding a Grade 1, Grade 2, or Grade 3 butt log when it reached 16 inches in diameter at breast height (d.b.h.). The grades were developed from tree-growth characteristics and stem defects located on the butt 16-foot log section. Many of the same growth characteristics and defect indicators were further quantified by Sonderman and Brisbin (1978), who developed a quality classification system that describes the relative quality of individual trees. More recently, Dale and Sonderman (1984) investigated growth and quality changes resulting from the effects of different thinning methods on white oak trees. These studies have produced a data base that can be used for future research on predicting tree quality in young growing-stock trees.

This study compares quality and growth changes over time of hardwood growing-stock trees by the provisional tree grades. Data on tree-grade changes provide a standard for evaluating how different tree species perform under different thinning treatments, and aid the forester and land manager in selecting the best thinning method.

The Stands

The study trees were located on four forest stands at the Vinton Furnace Experimental Forest in southeastern Ohio. The original stands contained mixtures of mature, even-aged, upland hardwood species on medium to good sites. One of the stands was clearcut in 1954 and the other three between 1959 and 1963. Before cutting, all of the stands were uniform with respect to site class, species composition, and quality. They differed only in age, which at the time of thinning was between 14 and 23 years. In 1977, the stands were thinned to 30, 50, and 70 percent of full stocking according to Gingrich (1967), and a crop-tree release was established. All 88 plots, including the controls, were 1/10-acre in size. A 1/2-chain-wide isolation strip was placed around each treatment boundary and treated the same as the respective plots; 351 trees were measured in this study. At the time of thinning, species composition included mixed oaks, aspen, yellow-poplar, red maple, black cherry, black walnut, blackgum, butternut, beech, red elm, and hickory. Four species that represented the majority of the stands were grouped and used for the analyses. They were oak, yellow-poplar, red maple, and aspen. Miscellaneous species were not included in the analyses because of a small number of sample trees.

Methods

The selected trees were graded twice (1977 and 1983) by the provisional grade specifications for hardwood growing-stock trees (Boyce and Carpenter 1968). Specifications required tree d.b.h. to be 6.0 inches or larger and that each tree have a potential 12-, 14-, or 16-foot butt log. Each tree was graded and assigned to one of four provisional growing-stock tree grades (the fourth grade was added for trees not qualifying as Grade 1, 2, or 3, but still meeting criteria for butt-log length). All of the grades were assigned according to the probability that a tree will yield a Grade 1, 2, or 3 butt log when it reaches 16 inches in d.b.h. The provisional tree grades were defined as:

- Grade 1: Crown class must be dominant or codominant, up to 4 inches of sweep allowed, and up to four defects permitted.[1]
- Grade 2: Crown class must be dominant or codominant, up to 6 inches of sweep allowed, and 5 to 17 defects permitted.[1]
- Grade 3: Admit all crown classes, up to 8 inches of sweep, and 18 to 30 defects permitted.[1]
- Grade 4: Include all trees not meeting Grade 1, 2, or 3 specifications but still meeting criteria for butt-log length.[1]

For the analyses, the trees were grouped by species, treatment, provisional grade, and year measured. The differences in potential grade change between growth periods (years) were the basis for this paper.

[1]Defects include limbs, overgrowths, knots, bud clusters, and bark distortions. Trees with any amount of rot or forks are automatically Grade 4.

Results and Discussion

This paper focuses on stem quality as reflected in potential tree-grade changes over time under different thinning treatments. However, tree growth is as important as tree quality since both are taking place at the same time. For instance, as a tree grows, the branches may develop into live limbs, the live limbs die, and the dead limbs become overgrowths. The speed of this process is controlled partially by stand density, age, and site.

Oak

The oaks species generally developed more stem defects from heavy thinnings and consequently had lower grades than some of the other species in this report. In fact, the open crown condition of the 30 percent treatment had an adverse effect on oak stem quality and grade (Fig. 1).

Because of the many stem defects, there were no Grade 1 oak trees in the 30 percent treatment. The percentage of Grade 2 oak trees declined and the proportion of Grade 3 and Grade 4 trees increased. The percent decline in Grade 2 trees was due to an increase in the number of stem defects resulting from excessive sunlight that caused many of the suppressed buds to sprout and "feather out" as new epicormic branches. At the same time, some of the existing live limbs continue to thrive in the sunlight and grow larger, adding to the number and seriousness of the stem defects.

There were no Grade 1 oak trees in the 50 percent treatment for the same reasons as in the 30 percent treatment—excessive stem defects. The percentage of Grade 2 oak trees did not change, but there was a slight increase in Grade 3 trees in this treatment.

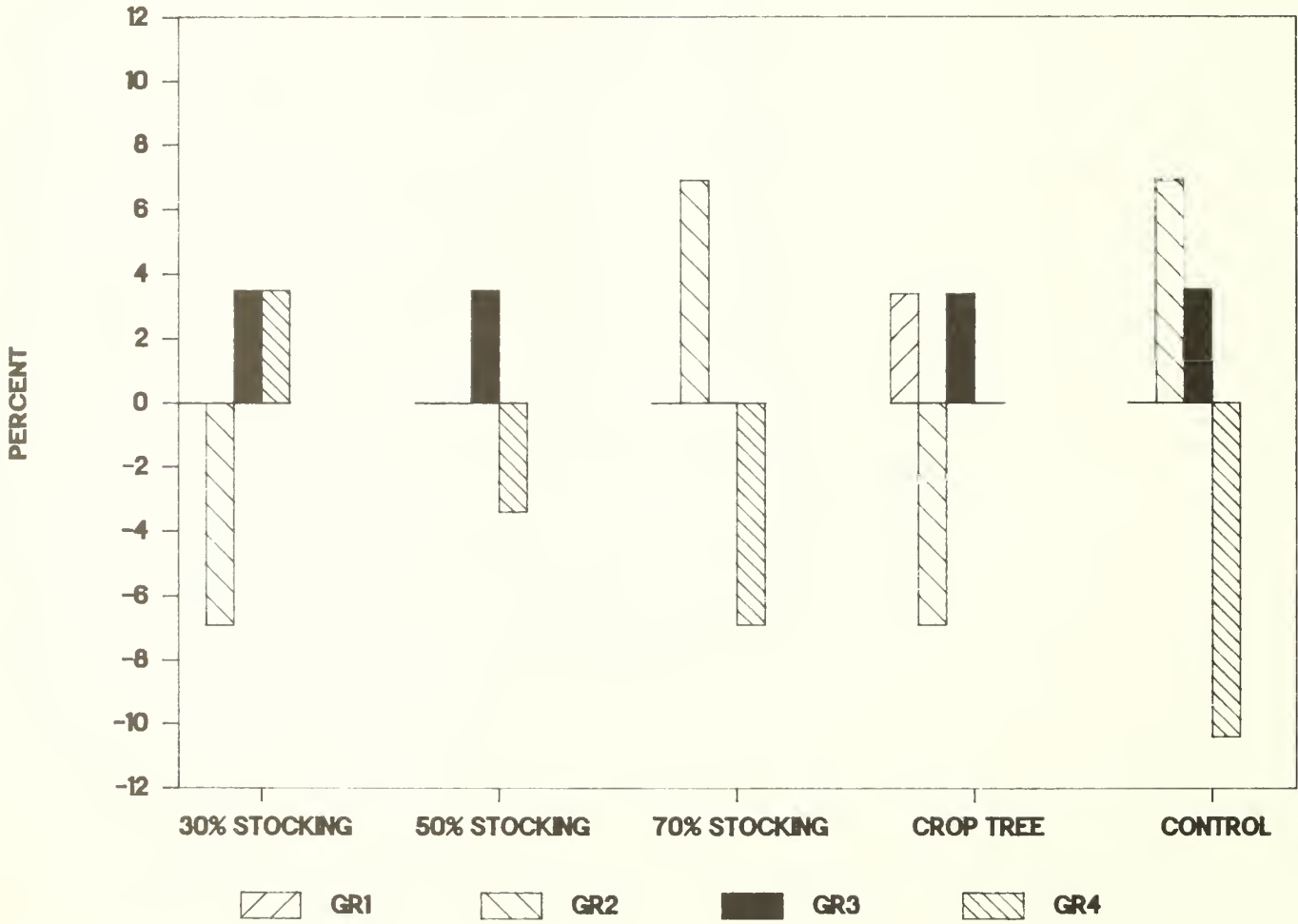

Figure 1.—Percent change in oak provisional tree grades, by treatment, 1977-83.

For the same reasons cited, there were no Grade 1 oak trees in the 70 percent treatment; however, the proportion of Grade 2 oaks increased by about 7 percent, the Grade 3 oak trees remained constant, and the Grade 4 trees decreased. As thinning intensities decreased, there was a trend toward better tree grades for the oak species.

The crop-tree release resulted in the greatest improvement, a 3-percent increase in Grade 1 trees and a 7-percent decrease in Grade 2 trees. Grade 3 crop trees increased slightly, but there was no change in the percentage of Grade 4 trees. The crop-tree treatment, which favors dominant and codominant trees in the final stand, resulted in fewer epicormic branches from reduced sprouting that is associated with better crown classes. This supports previous studies that show an inverse relationship between crown dominance and sprouting.

In the control plots, the natural pruning of the dead limbs resulted in fewer stem defects and a 10-percent decrease in Grade 4 oak trees. This percentage change was redistributed among Grade 2 and Grade 3 trees as an increase. There were no Grade 1 trees in the control.

Many of these results are similar to those of a thinning-intensity study (Sonderman 1984) that showed a loss of stem quality as a result of heavy thinning in 80-year-old white oaks.

Yellow-Poplar

Previous research has shown that yellow-poplar trees sprout with epicormic branches if exposed to heavy thinning. During this 6-year study period, several yellow-poplar in the 30 percent treatment (Fig. 2) did increase in quality to Grade 1. However, a larger proportion, more than 13 per-

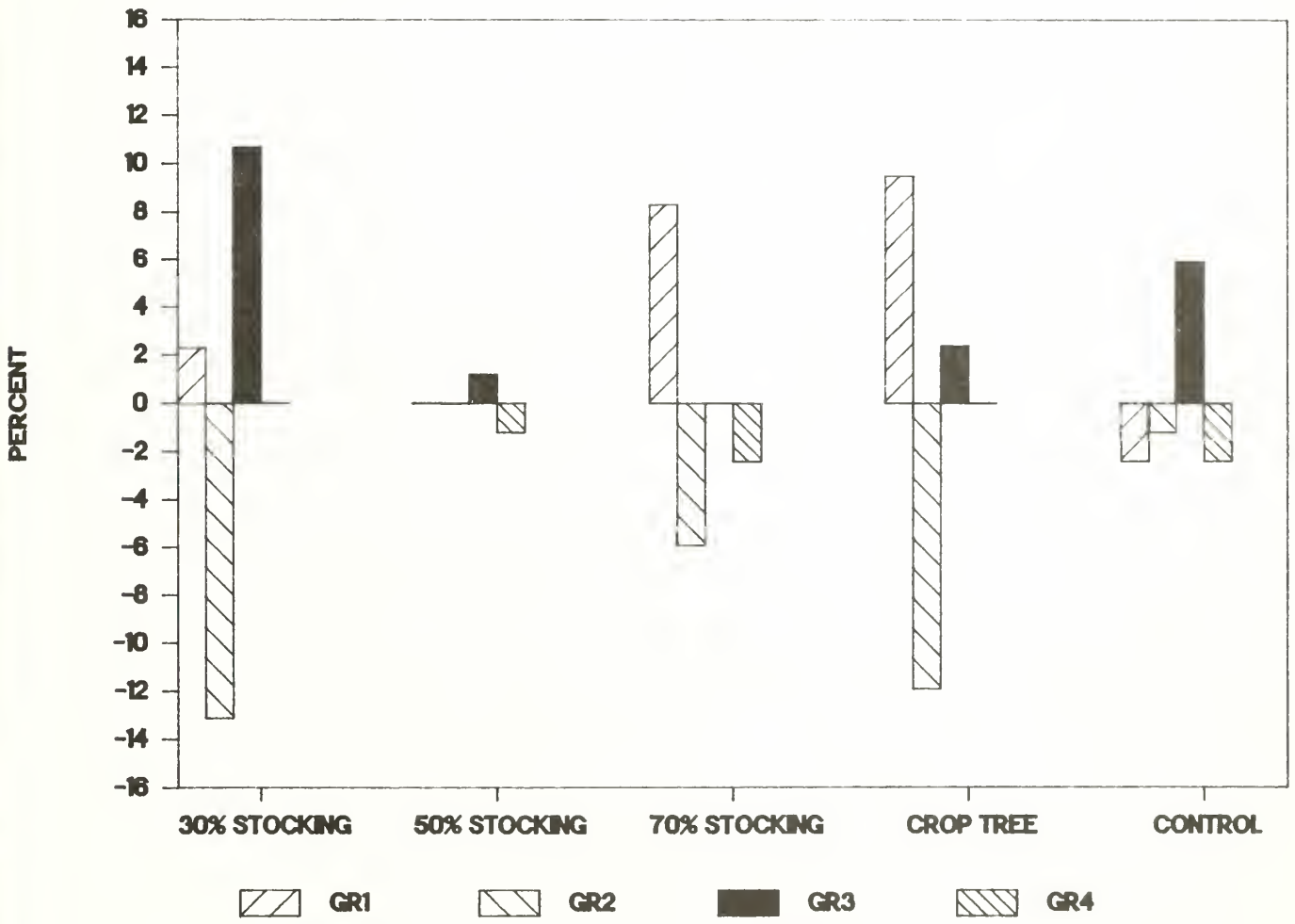

Figure 2.—Percent change in yellow-poplar provisional tree grades, by treatment, 1977-83.

cent, decreased from Grade 2 to Grade 3. Many of the original Grade 2 trees became Grade 3 trees because of an increase in the number of stem defects resulting from heavy thinning. The Grade 4 yellow-poplar trees in the 30 percent treatment were unchanged.

There were no Grade 1 yellow-poplar trees in the 50 percent treatment. However, the effects of this thinning treatment resulted in no change in the proportion of Grade 2 trees, and only a slight increase in Grade 3 trees. This small increase in Grade 3 trees resulted from fewer stem defects in the Grade 4 trees after 6 years.

The 70 percent treatment had a dramatic effect on the percentage of yellow-poplar Grade 1 trees—the proportion of these trees increased by 8 percent from 1977 to 1983. Many of these originally were Grade 2 trees that developed better quality and grade over time by losing a number of limb defects. There was no change in the proportion of Grade 3 trees and a slight decrease in the proportion of Grade 4 trees in the 70 percent treatment.

The effects of crop-tree thining on yellow-poplar resulted in a substantial increase in Grade 1 trees, with an almost equal loss in Grade 2 trees. Obviously, they changed grade because of fewer stem defects. Yellow-poplar responded well to crop-tree thinning with very little sprouting of epicormic branches. The proportion of Grade 3 trees increased by about 2 percent and there were no Grade 4 trees.

The results of the controls on yellow-poplar had an opposite effect from that of the crop-tree treatment. A small percentage loss of Grade 1 and Grade 2 trees was noted along with a 6-percent increase in Grade 3 trees. Most of the young trees in the control treatment grew closer together and were more uniform than in the other treatments, resulting in an overall lower crown dominance, smaller crown ratios, and fewer vigorous stems. These factors contributed to the increase in the proportion of Grade 3 trees, most of which originated from a combined change of Grade 1, 2, and 4 trees. It should be noted that the self-pruning that did occur was offset by the growth factors cited.

Red Maple

Red maple trees usually are considered prolific epicormic sprouters when subjected to heavy thinnings. These heavy thinnings can be expected to deteriorate red maple quality (grade) over time as a result of an increase in the size and number of limb-related defects. The many defects that resulted from this sprouting help explain why there were no Grade 1 trees in the 30 percent treatment and why Grade 2 and Grade 3 red maple trees (Fig. 3) increased only about 2 percent each. Heavy thinning causes young red maple crowns to expand and extend downward, resulting in an increase in crown ratios. Over time, increases in crown ratio reflect the degrading effect that results from the development of excessive epicormic branches and live limbs. In addition to these changes in crown ratio, the losses in the percentage of Grade 4 red maple trees may also result from a change in crown class that was created by the heavy thinning and, thus, reflected in the grading specifications.

There were no graded red maple trees in the 50 percent treatment.

There were no Grade 1 red maple trees in the 70 percent treatment, but there was a 4-percent increase in Grade 2 trees. The percentage of Grade 3 and Grade 4 trees decreased, probably as a result of the decrease in the number of limb defects. The combination of all of these changes resulted in better overall tree quality in the 70 percent treatment.

Crop-tree thinning of red maples resulted in good volume growth and quality development. The increase in the percentage of Grade 1 trees was a direct result of less sprouting from dominant and codominant trees as opposed to the intermediate and suppressed trees. It is believed that genetically inferior trees (with regard to growth rate) tend to be found in the intermediate and suppressed crown classes, and that these trees tend to sprout more prolifically than the genetically superior trees (dominant and codominants).

There were no Grade 1 red maple trees in the control. The percentage of Grade 2 red maples decreased and the percentage of Grade 3 red maples increased correspondingly. The formation of new epicormic branches, along with existing large live and dead limbs that do not prune-off easily or quickly, contributed to lower grades for red maple trees. Besides the number of limbs, some of the lower grades were caused by poorer crown classes in the control plots. Many of these crown classes were in the codominant and intermediate categories, which have lower quality factors in the provisional tree-grading specifications.

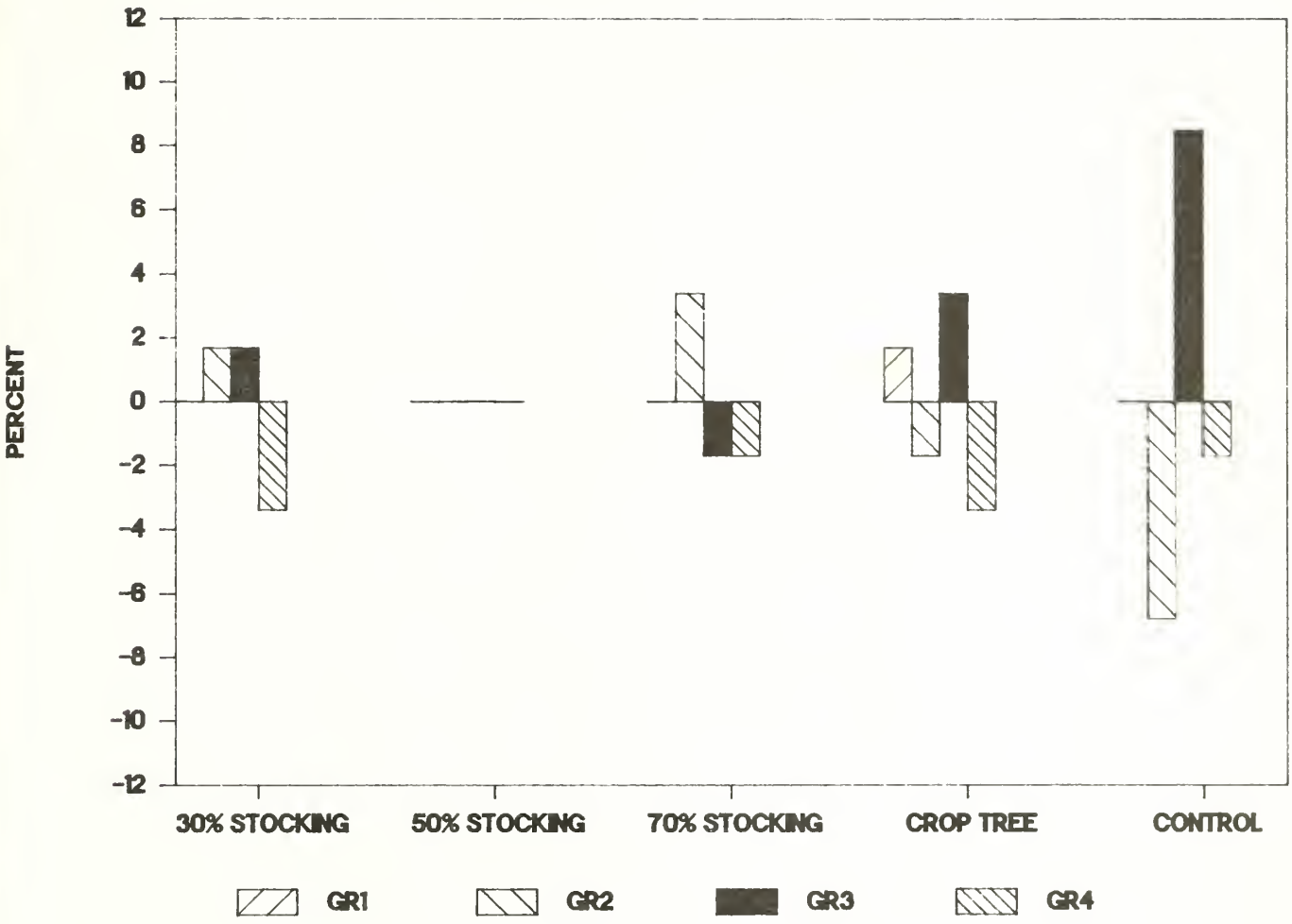

Figure 3.—Percent change in red maple provisional tree grades, by treatment, 1977-83.

Aspen

Aspen is a short-lived species that does not respond well to thinning—whether heavy or light. Results from the 30 percent treatment (Fig. 4) show no Grade 1 trees and a 3-percent increase in Grade 2 trees. Many of the aspens in the poorer grades lost limbs during the 6-year study period, accounting for most of the changes.

Aspen, however, did show an increase in Grade 1 trees in the 50 percent, 70 percent, crop-tree treatments, and control, but the grade increases resulted more from loss of limbs from age than from the effects of thinning. Limbs on aspen trees between 20 and 30 years of age tend to die early or persist only for a few years under any stocking treatment.

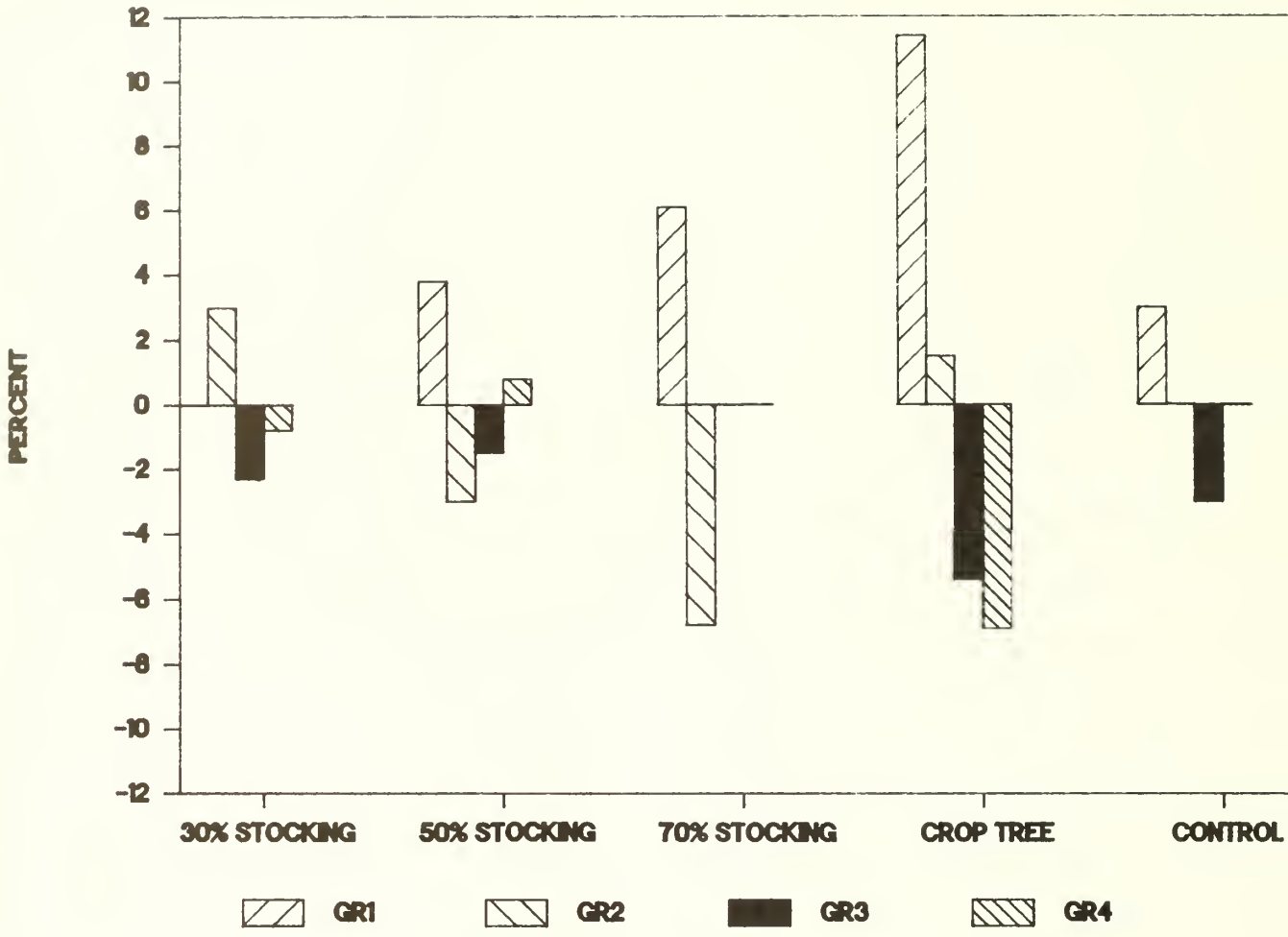

Figure 4.—Percent change in aspen provisional tree grades, by treatment, 1977-83.

Summary and Conclusions

The provisional tree-grade specifications for young growing-stock trees were based on crown position, stem form, and the number of surface-defect indicators. Comparing the data from 1977 and 1983 has shown a number of interesting changes. For example, the crown classes of many trees were changed by the thinning method applied. Heavy thinning tended to favor dominant and codominant trees in the residual stands, many of which suffered from excessive epicormic branching and heavy limb retention. In the 30 and 50 percent treatments, for example, the additional limb defects resulted in lower overall tree quality and grade than those in the 70 percent treatment. In the crop-tree treatment, the greatest improvement was in the percentage of Grade 1 trees. Thinning around young potential crop trees had a positive effect on the proportion of Grade trees because enough crown cover was maintained to partially shade the stem and still allow sufficient light for good growth. By contrast, the young trees in the control plots showed much slower diameter growth, almost equal height growth, more natural pruning of smaller limbs, and poorer but more evenly distributed crowns. This resulted in the larger limbs remaining on the stem, fewer epicormic branches, slightly straighter boles, and little positive effect on grade change for the trees in the control.

An overall look at all species combined by treatments (Fig. 5) shows the largest increase in Grade 1 trees in the crop-tree treatment and the smallest change in the control. There was a gradual increase in Grade 1 trees as percent stocking increased.

Other findings were:

- In the oak group, only the crop-tree release contained Grade 1 trees.
- Yellow-poplar was the only species with Grade 1 trees in the 30 percent treatment.
- There were no Grade 4 yellow-poplar trees in the 30 percent or crop-tree treatments.
- In the red maple group, only the crop-tree treatment contained Grade 1 trees.
- There were Grade 1 aspen trees in all treatments except for the 30 percent treatment.

The results indicate that the potential for growing Grade 1, high-quality, young hardwood trees increases with a decrease in thinning intensity. Thinning below 60 percent stocking has a detrimental effect on tree quality and grade. At this stocking level, a sufficient number of young trees will be able to fully utilize the site while maintaining good growth and quality.

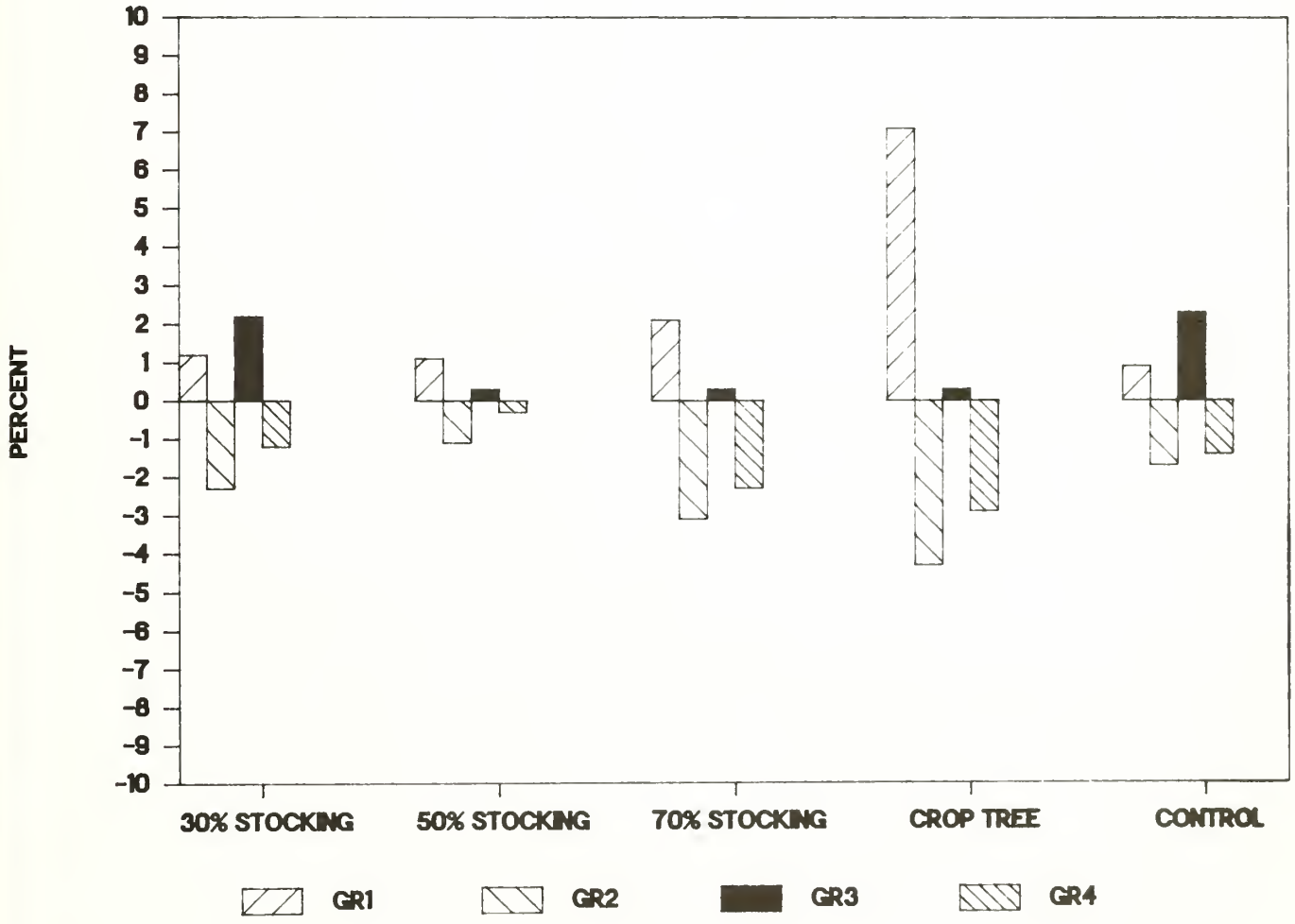

Figure 5.—Percent change in provisional tree grades for all species combined, by treatment, 1977-83.

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Sonderman, David L.; Rast, Everette D. 1987. **Changes in hardwood growing-stock tree grades.** Res. Pap. NE-608. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 8 p.

Describes changes in provisional tree grades for 351 young, mixed upland hardwood trees 6 years after thinning. Treatments of 30, 50, and 70 percent stocking plus a crop-tree release were applied. Results indicate that light thinning and crop-tree thinning produced higher quality and better grade trees than heavy thinning.

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Keywords: Stand density; thinning; stem quality; grade

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NE-RP-609

Estimating Yarding Costs For the Clearwater Cable Yarder

Chris B. LeDoux

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Abstract

Describes an equation that can be used to estimate yarding costs for the Clearwater cable yarder in clearcuts and light and heavy thinnings in eastern hardwoods. Yarding costs can be estimated with a hand-held calculator or the data can be incorporated into stump-to-mill desktop and mainframe computer programs.

The Author

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Introduction

Recent interest in promoting cable logging technology in the Eastern United States (Paul 1980; VPI&SU 1982) has led to production tests for and the development of a detailed, stump-to-mill cost-estimating package (LeDoux 1985) for six cable yarders of various sizes and capacities. These include the Appalachian Thinner, Bitterroot, Ecologger I, Koller K-300. Skylok 78, and Urus 1000-3. The cost equations for stump-to-mill timber production reflect conditions that would be encountered when logging hardwoods on steep, mountainous terrain in the Eastern United States.

A seventh system, the Clearwater yarder developed by the USDA Forest Service (USDA Forest Service 1981), was field tested in the Eastern Adirondack region of New York State (Bragg 1985; LeDoux and Peters 1985) and elsewhere (Till 1980; Sherar and Koger 1984), and subjected to comparative analysis (Sherar 1980; Walbridge et al. 1980; Gorsh 1983).

For this study, detailed time and motion data from the New York field studies, 1987 new equipment, labor, and fuel costs (Table 1), and the THIN yarding simulation model (LeDoux and Butler 1981) were used to develop a general equation for estimating yarding costs for the Clearwater yarder in eastern hardwoods for various stand conditions and silvicultural treatments. The cost equation was then used to compare the Clearwater yarder with the six previously mentioned systems.

Table 1.—Hourly yarding costs (1987) for the Clearwater yarder (includes all new equipment)

Item	Dollars/hr
Yarder and truck carrier	38.05[a]
Chain saws (3)	3.58
Labor	27.00[b]
Carriage	0.67
Radio signal (3 transmitters)	1.15
Total	70.45

[a]Includes depreciation, insurance, interest, and operating costs (fuel, oil, lubricants, maintenance, repair, taxes, and rigging) for the yarder and carrier.
[b]One yarder engineer, two chokersetters, one chaser; rates from "Cost Guide for Empirical Appraisals," USDA Forest Service, Region 9, Amendment 112.

Yarding Cost Equation

Simulated, delay-free data points for yarding cost were developed for the Clearwater yarder for a range of diameters (DBH), average slope yarding distances (SYD), and volumes cut per acre (VOAC). The stands chosen were from forest model plots of eastern hardwoods (Table 2). Each stand was thinned using a d/D ratio (arithmetic mean diameter of cut trees/arithmetic mean diameter of stand) of 1.0 to levels of 30 percent, 50 percent, and then clearcut. The trees cut from each treatment were bucked into logs[1] (LeDoux 1986). The THIN model (LeDoux and Butler 1981) and time-study data cited previously were used to develop the delay-free data points through numerous simulations. The simulated data points were pooled to develop a delay-free cost equation for the Clearwater yarder. Nonlinear

Table 2.—Stand data for eight forest model plots

Plot	Average d.b.a.[a]	Merchantable volume[b]	No. trees per acre[c]
	Inches	*Ft*^{3}	
A2	7.2	2652	222
B10	8.1	2528	214
C8	9.1	3556	245
D14	11.6	3124	166
E13	12.7	4922	183
F4	16.8	6315	176
G4M	20.4	6466	162
H4M	24.0	6871	174

[a]Includes trees 5.0 inches or larger in d.b.h.
[b]Logs less than 4 feet long and less than 4 inches top diameter not included.

[1]LeDoux, C. B. 1984. Hardwood log bucking simulator. Unpublished computer program on file at the Northeastern Forest Experiment Station, 180 Canfield Street. P. O. Box 4360. Morgantown, West Virginia 26505.

multiple regression analysis was used to summarize the delay-free data points and the independent variables:

Dollars/ft^3 = 0.12577
- 0.00328 (DBH)
+ 0.000048 (SYD)
+ 623.08404 (1/(VOAC * DBH))

R^2 = 0.582

where:

DBH = Arithmetic mean tree diameter at breast height, in inches; variable limits = 4 to 16 inches

SYD = Average slope yarding distance, in feet; variable limits = 50 to 900 feet

VOAC = Average volume removed per acre, in ft^3; variable limits = 780 to 6,871 ft^3

The equation is machine-specific and the variable limits should be observed carefully.

The delay-free cost must be adjusted to allow for nonproductive time. Delay percentage is the proportion of nonproductive time expressed as a percentage of total time. One minus the proportion of nonproductive time is the proportion of productive time. For example, if the delay is 10 percent, the proportion of nonproductive time is 0.1, and the proportion of productive time is 0.9. The delay-free cost is adjusted by dividing it by the proportion of productive time to obtain the cost with delay.

Yarding Delays

The observed productive time for the Clearwater yarder was only 40 percent of total time; however, this low time was due to the unexpected (and rare) breakdown of the skyline and mainline. Eliminating this delay would result in a productive rate of nearly 60 percent, which compares favorably with the other cable systems mentioned (LeDoux 1985). Productive delays accounted for 14.5 percent of total time and nonproductive delays 45.5 percent. The following is a breakdown of the nonproductive and productive delays with the Clearwater yarder:

Delay	Percent
Nonproductive	
Broken skyline	60.3
Broken mainline	35.1
Loose hydraulic hose	0.5
Fix stop	0.4
Miscellaneous	3.7
Total	100.0
Productive	
Hangups	47.3
Wait on skidder	20.3
Move stop	16.7
Tangled mainline	11.3
Hit stop	2.4
Slipped choker	2.0
Total	100.0

The delay percentages can be used to adjust the delay-free cost estimates. For example, a logger is estimating yarding costs for a hardwood stand with an average arithmetic tree d.b.h. of 8.0 inches, an average slope distance of 200 feet, and an average volume removal of 2,000 ft^3. The delay-free yarding cost is:

= 0.12577
- 0.00328 (8)
+ 0.000048 (200)
+ 623.08404 (1/(2000 * 8))
= 0.148

Adjusting the delay-free cost with an average delay percentage of 0.23 (LeDoux 1985) = 0.148(1-0.23) = 0.148/0.77 or \$0.192/ft^3. Users may wish to substitute delay percentages based on their own observations.

Applying the Cost Equation

Yarding costs can be estimated with a hand-held calculator or the data can be incorporated into stump-to-mill desktop and mainframe computer programs. Information on the arithmetic mean d.b.h. to be harvested, average slope yarding distance, and average volume cut per acre can be obtained from the inventory and cruise data and the logging plan for the tract. Figure 1 shows the impact of silvicultural treatment on yarding cost. Heavy-volume removals reduce yarding costs; the reverse is true for low removals. Information such as that in Figure 1 also can be used to plan harvesting limits. For example, a logger is allowed \$0.12/ft^3 for the yarding operation. Projecting a line representing 0.12/ft^3 on Figure 1 shows that the break-even points require harvesting limits of 9.5, 12.0, and 14.5 inches d.b.h. for clearcuts, heavy, and light thinnings, respectively.

Clearwater Versus Other Yarders

The Clearwater Yarder is competitive with the Appalachian Thinner in the d.b.h. range of 7 to 10 inches, and with the Koller K-300 and the Ecologger I in the range of 7 to 16 inches (Fig. 2). It is important to note that the competitive ranking of these machines will be affected by differences in factors such as initial investment, salvage value, crew size required, payload capacity, and line speed. Also, the comparisons shown are based on specific sets of stand conditions and will change accordingly with changes in slope yarding distance and volume removal.

Because of its limited capacity (3,500 pounds), the Clearwater yarder cannot bring in heavy loads to increase production and reduce the cost per unit produced. In this study, the actual working payload was about 1,250 pounds, rather low for a system that costs about \$95,000. Also, the limited mainline pull (7,500 pounds) of this machine resulted in significant delays in breaking the turn of hooked logs from their lay. Sherar and Koger (1984) reported that increased mainline pull would result in fewer delays.

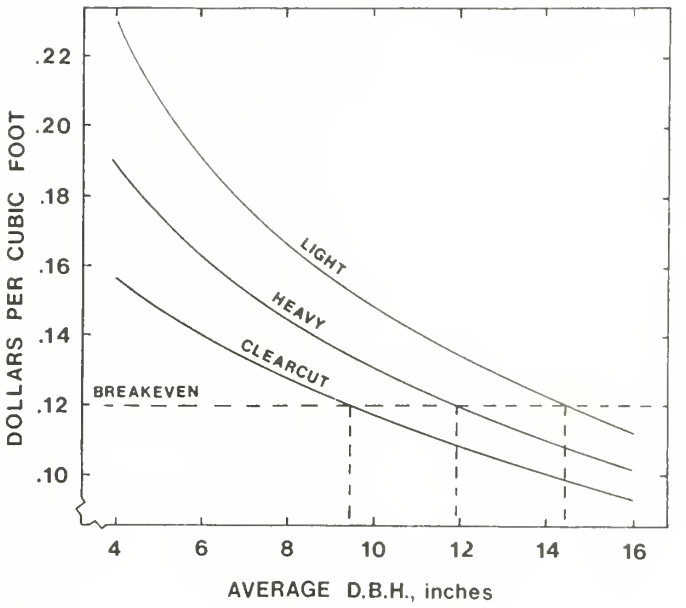

Figure 1.—Simulated yarding cost and break-even points by silvicultural treatment for the Clearwater yarder.

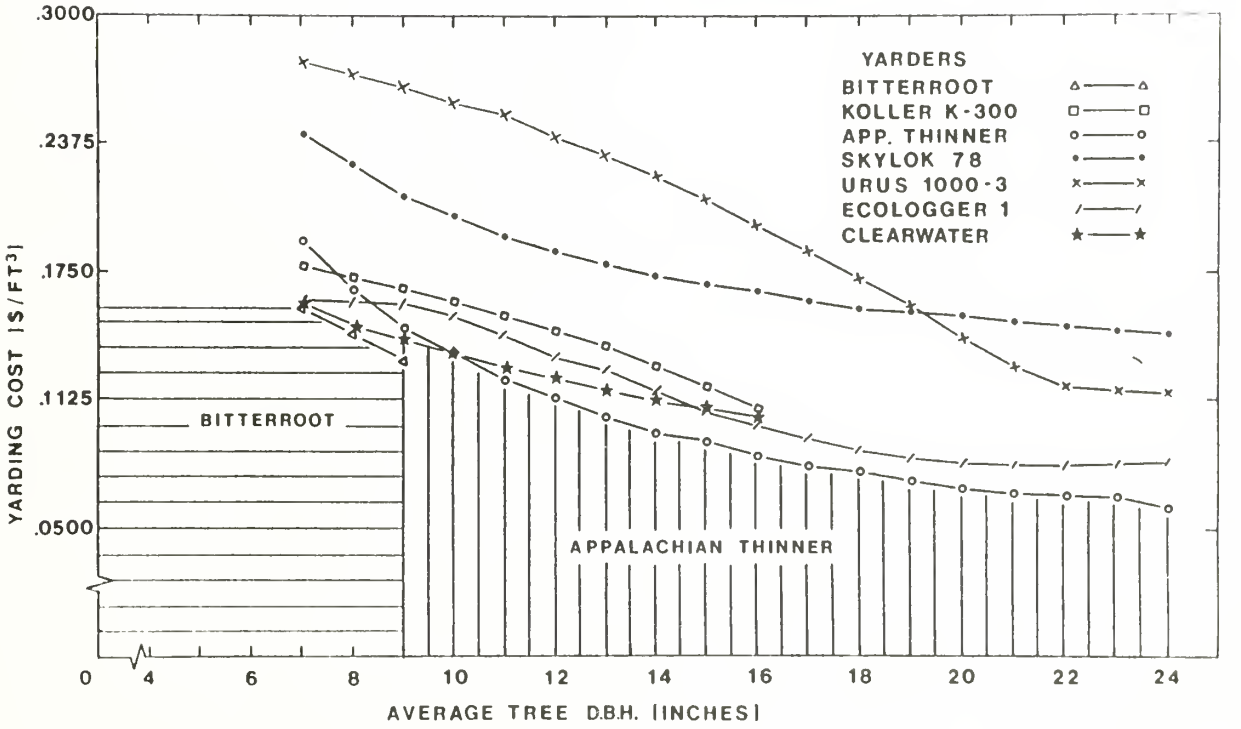

Figure 2.—Simulated comparison of seven cable yarders by average tree d.b.h. (SYD = 200 feet; VOAC = 2,000 ft³). Shaded areas indicate diameter range best suited for individual machines.

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LeDoux, Chris B. 1987. **Estimating yarding costs for the Clearwater yarder.** Res. Pap. NE-609. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 4 p.

Describes an equation that can be used to estimate yarding costs for the Clearwater yarder in clearcuts and light and heavy thinnings in eastern hardwoods. Yarding costs can be estimated with a hand-held calculator or the data can be incorporated into stump-to-mill desktop and mainframe computer programs.

ODC 377.2 (74/75)

Keywords: Yarding costs, simulation, delays

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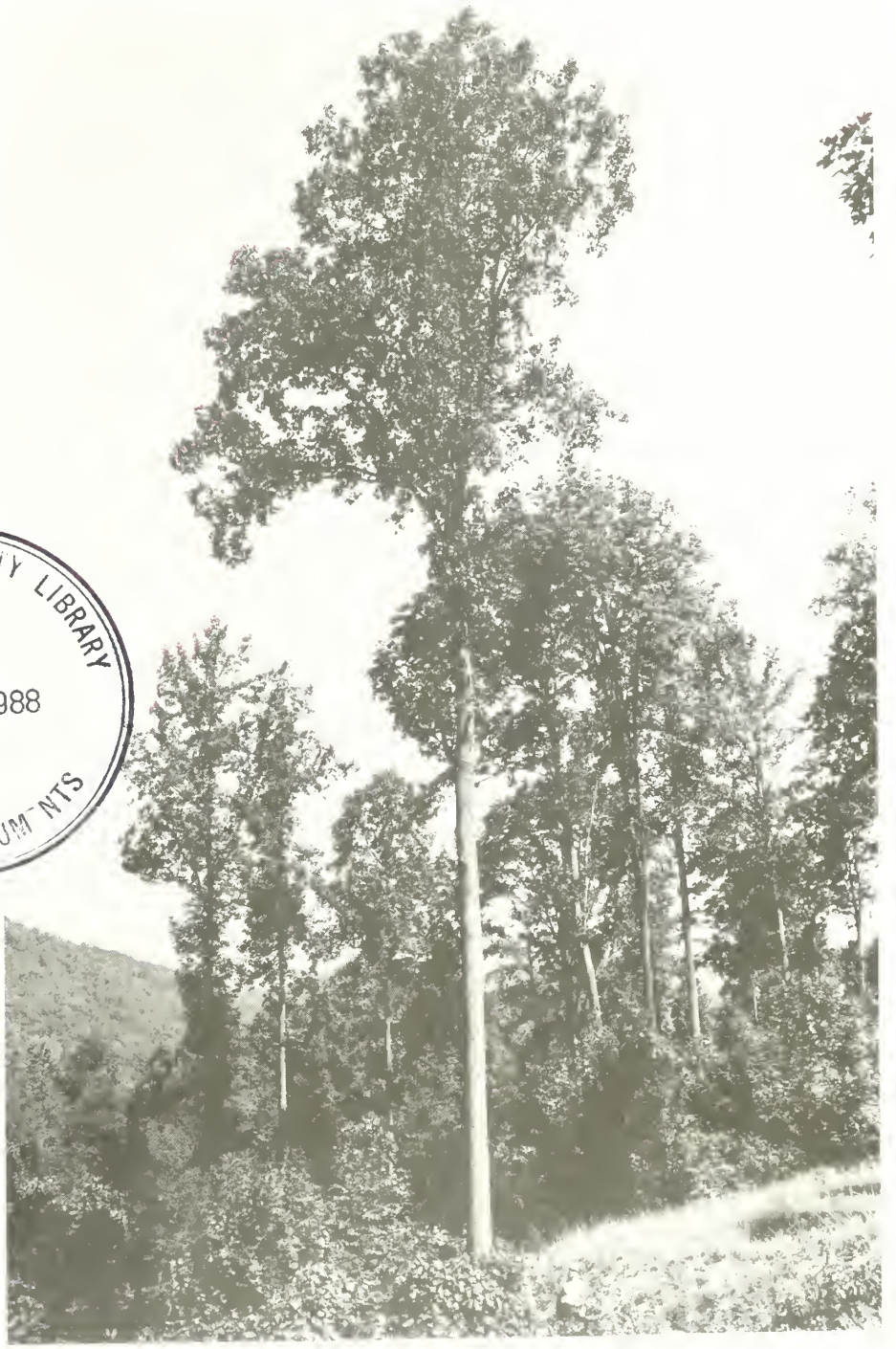
**Northeastern Forest
Experiment Station**

Research Paper NE-610

D.b.h./Crown Diameter Relationships in Mixed Appalachian Hardwood Stands

Neil I. Lamson



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Abstract

Linear regression formulae for predicting crown diameter as a function of stem diameter are presented for nine species found in 50- to 80-year-old mixed hardwood stands in north-central West Virginia. Generally, crown diameter was closely related to tolerance; more tolerant species had larger crowns.

The Author

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Introduction

In order to apply any silvicultural system, it is essential to understand how trees grow and react to various cultural treatments. Growth rates of trees are directly affected by the intensity of competition. Crown dimensions are feasible expressions of the cumulative effects of competition (Curtis 1970, Krajicek et al. 1961). This paper reports diameter breast height (d.b.h.)/crown diameter relationships for unmanaged, even-aged mixed hardwood stands in West Virginia.

Methods

Nine species were selected for study: hickory (Carya cordiformis and Carya ovata), northern red oak (Quercus rubra L.), scarlet oak (Quercus coccinea Muenchh.), white ash (Fraxinus americana L.), yellow-poplar (Liriodendron tulipifera L.), black cherry (Prunus serotina Ehrh.), sugar maple (Acer saccharum Marsh.), red maple (Acer rubrum L.), and beech (Fagus spp.). These are common species in mixed hardwood stands in the central Appalachian mountains. Data were collected from a total of 52 even-aged stands ranging in ages from 50 to 80 years and located in north-central West Virginia. These were typical second-growth stands with scattered individual trees up to 150 years old.

Northern red oak site index (SI) class ranged from 55 to 85 feet in stands estimated by using height/age relationships (Schnur 1937). Within each stand, trees of the study species were randomly selected. All crown classes were included so long as the trees were reasonably healthy and had normal crowns that showed no signs of damage such as top breakage or disease. For each study tree, diameter outside bark at 4.5 feet (d.b.h.) and crown diameter along two axes were measured. Crown diameter was measured by two people using a 100-foot tape and ocularly estimating the crown edges. A total of 1,955 study trees were included with 98 to 549 trees for each of the nine study species. D.b.h. ranged from 3.0 to 36.3 inches, and crown width ranged from 5 to 70 feet.

All data were grouped by species and 10-foot red oak site index class. For each group, the data were fit to the following equations:

$$CD = a + b(D)$$
$$CD = a + b(D^2)$$
$$CD = a + b(D) + C(D)^2$$
$$CD = a + b(\log(D))$$
$$\text{Log}(CD) = a + b(D)$$
$$\text{Log}CD = a + b(\log(D))$$
$$1/CD = a + b(D)$$
$$1/CD = a + b(a/D)$$

where CD = crown diameter
D = d.b.h.

Results

Equation Selection

None of the data transformations gave a better fit than the linear regression using only D. Therefore, the linear regression form of CD = a +b(D) was selected.

Differences Due to Site Index

Except for scarlet oak, which was observed only in SI class 60 stands, all species were observed in stands in which the SI class ranged from 60 to 70, 60 to 80, or 70 to 80 feet. Differences due to SI class were tested by statistically comparing the slopes and intercepts of each species/site index class equation to those from a single species equation using the data from all trees for a species regardless of site index class. Significant differences were found among the SI classes only for red oak and yellow-poplar. For red oak, SI 70 and 80 were not different.

Differences Among Species

Differences among species were tested by statistically comparing slopes and intercepts of individual species equations to those from equations which included all trees from two or more species. No significant differences were found among hickory, red oak SI 70 and 80, scarlet oak, and white ash. Also red oak SI 60, red maple and black cherry were not significantly different. Therefore, equations for the white ash, hickory, red oak SI 70 and 80, and scarlet oak group and the red oak SI 60, red maple, black cherry group were calculated. The resultant six equations are shown in Table 1. Coefficients of determination (R^2) ranged from 0.59 to 0.68 for the six equations. Intercepts (a) ranged from 4.951 feet for yellow-poplar, site index 80, to 17.845 for sugar maple, while slopes (b) ranged from 1.022 for sugar maple to 2.030 for the yellow-poplar, SI 80 (Table 1).

Table 1.—Slopes (b) and intercepts (a) for linear regression equations crown diameter =a +b(d.b.h.)

Equation No.	Species	No. of observations	a	b	r^2	SE(a)
1	Beech	98	16.734	1.291	0.61	1.665
2	Sugar maple	241	17.845	1.022	0.68	0.691
3	White ash/ oak group[1]	607	13.571	1.318	0.59	0.768
4	Red maple, black cherry[2]	566	12.596	1.073	0.62	0.518
5	Yellow-poplar, SI 70	109	5.203	1.383	0.61	1.753
6	Yellow-poplar, SI 80	334	4.951	2.030	0.59	1.530

[1]Oak group contains hickory, scarlet oak, and red oak SI 70 and 80.

[2]Also includes red oak SI 60.

Validation of Equations

The six equations were validated by splitting the data into a regression data set and a test data set. The regression equations for the six species and SI classes were calculated using the regression data set and these equations were used to calculate predicted values and residuals for the test data set. The SAS procedure PROC MEANS (SAS 1985) was used on the residuals to test whether there were differences for each group and for the data set as a whole. The variance estimates of the residuals were also compared to the variances obtained with the regression data set. Since the variances of the two procedures were nearly identical and the tests indicated that none of the mean residuals were significantly different from zero, the equations were assumed to be valid.

Crown Diameters

Crown diameters calculated using the formulae from Table 1 are shown in Table 2. Yellow-poplar SI 70 and red maple/black cherry have the smallest crowns, while yellow-poplar SI 80 and beech have the largest. It is interesting to note that yellow-poplar SI 80 has the largest crowns for trees over 16 inches d.b.h. However, yellow-poplar over 16 inches d.b.h. have crowns only about 3 to 8 feet larger than beech.

Table 2.—Estimated crown diameter by 2-inch d.b.h. classes calculated using the formulae from Table 1.

Species	D.b.h. class 6	8	10	12	14	16	18	20	22	24	26
	Feet										
Beech	25	27	30	32	35	37	40	43	45	48	50
Sugar maple	24	26	28	30	32	34	36	38	40	42	44
White ash/oak group[1]	22	24	27	29	32	35	37	40	43	45	48
Red maple/black cherry group[2]	19	21	23	26	28	30	32	34	36	38	40
Yellow-poplar SI 70	14	16	19	22	25	27	30	33	36	38	41
Yellow-poplar SI 80	17	21	25	29	33	37	42	46	50	54	58

[1]Oak group contains hickory, scarlet oak, and red oak SI 70 and 80.

[2]Includes red oak SI 60.

Discussion

These equations and tables are based on data collected from even-aged stands that were 50 to 80 years old. Therefore, most of the 4- and 6-inch trees were overtopped, as were many of the 8-inch trees. These equations may not accurately describe d.b.h./crown diameter relationships of trees in stands less than 50 years old. For example, 6-inch SI 70 yellow-poplar trees in a 25-year-old stand will most likely be codominant and may not have crowns that are 14 feet in diameter as estimated in Table 2.

Generally, the intolerant species, black cherry and yellow-poplar SI 70, have the smallest crowns. Beech has the largest crowns for diameters up to 16 inches. Sugar maple has larger crowns than the white ash/oak group up to 14 inches d.b.h. However, for trees 20 inches d.b.h. and larger, the white ash/oak group, beech and sugar maple have crowns about the same size. Since most of the study trees at least 20 inches d.b.h. were codominant, it can be concluded that for these 50- to 80-year-old stands, codominant white ash/oak group species beech and sugar maple have about the same size crowns.

These crown diameter data suggest that there are three major species groups for trees at least 16 inches d.b.h. The first is beech and yellow-poplar SI 80, with the largest crowns. The second group, with intermediate-size crowns contains sugar maple, white ash, and the oaks. The third group, with the smallest crowns includes red maple, yellow-poplar SI 70, and black cherry. Growth and yield researchers working in these stands are investigating various even-age management strategies. If relative stand density (Marquis et al. 1984) proves to be a viable management tool in Appalachian hardwood stands, these three species groups may prove to be useful.

Leak (1983) reported that in New Hampshire beech also had larger crowns than sugar maple or red maple. Hough (1935) also found that young beech had the largest crowns in Pennsylvania hardwood stands. Lake States northern hardwoods have about the same size crowns as the Appalachian red maple/black cherry group (Godman and Tubbs 1973).

Conclusions

D.b.h. is a reasonably good predictor of crown diameter in 50- to 80-year-old even-aged Appalachian hardwood stands. In these mixed stands, beech has the largest crowns, while yellow-poplar SI 70 and black cherry have the smallest. Three general crown width groups are evident. Beech and yellow-poplar SI 80 have the largest crowns, followed by a second group of sugar maple, white ash, red oak, scarlet oak, and hickory. Red maple, yellow-poplar SI 70, and black cherry form the third group with the smallest crowns.

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Lamson, Neil I. 1987. **D.b.h./crown diameter relationships in mixed Appalachian hardwood stands.** Res. Pap. NE-610. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 3 p.

Linear regression formulae for predicting crown diameter as a function of stem diameter are presented for nine species found in 50- to 80-year-old mixed hardwood stands in north-central West Virginia. Generally, crown diameter was closely related to tolerance; more tolerant species had larger crowns.

Keywords: Crown diameter

ODC: 531 (Appalachian hardwoods):176.1

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